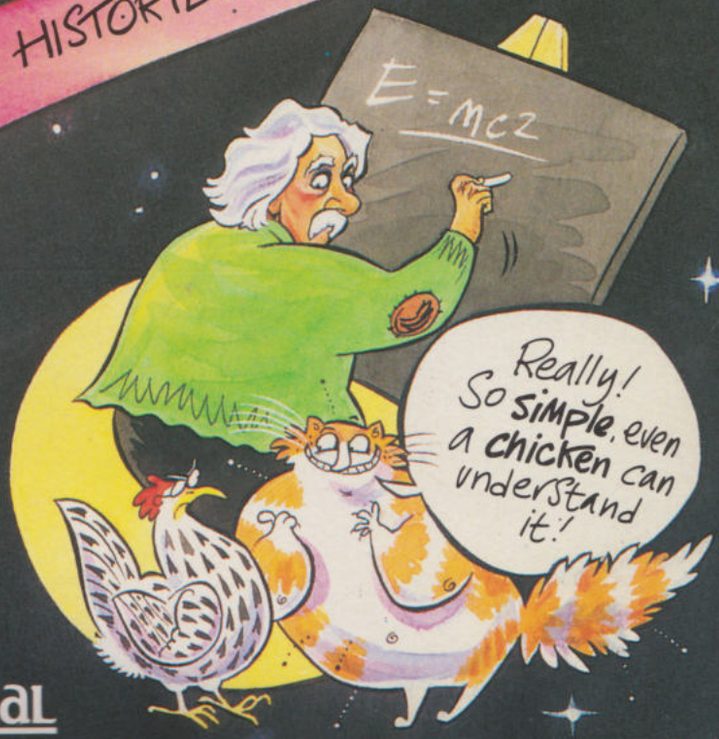
KATE CHARLESWORTH · JOHN GRIBBIN

THE CARTOON HISTORY OF TIME

REFRESHES PARTS OTHER TIME HISTORIES CANNOT REACH!



CARDINAL

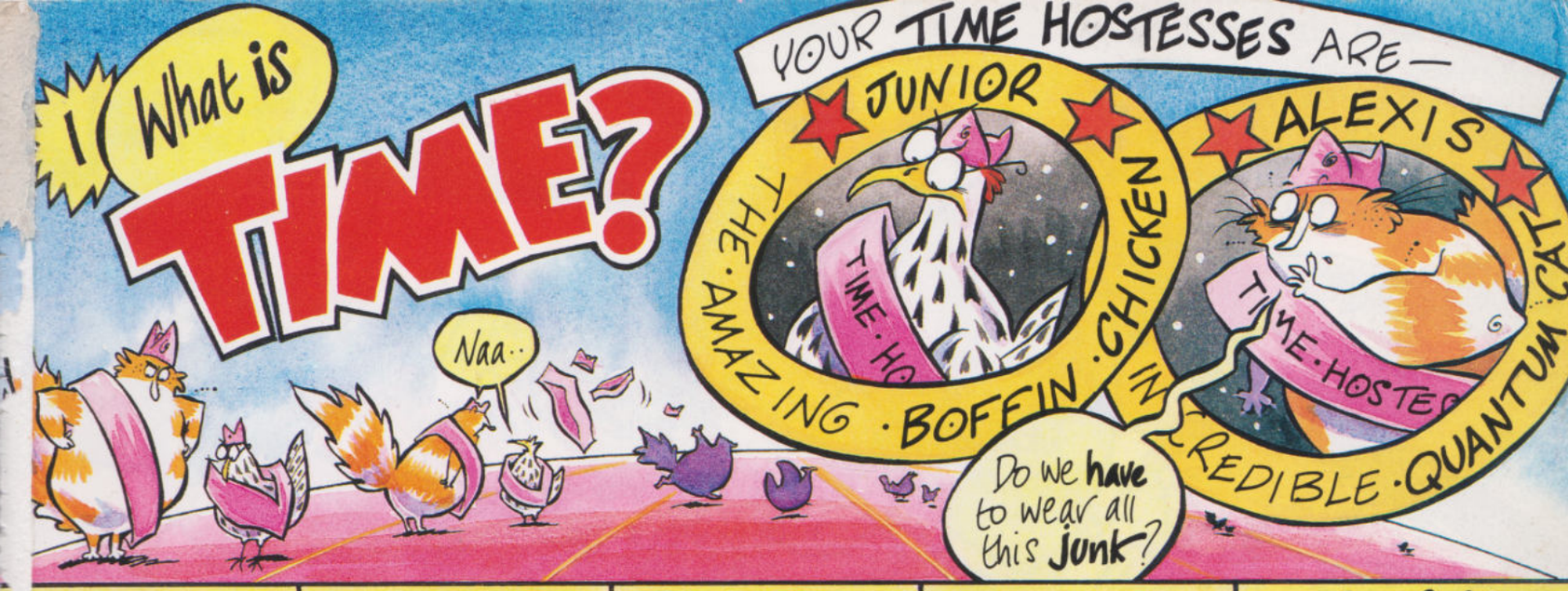
JUNIOR CHICKEN APPEARS WEEKLY WITH ALEXIS IN THEIR **NEW SCIENTIST** CARTOON STRIP ★ APART FROM A LITTLE LIGHT **RESEARCH**-UPDATING HER **PhD** THESIS ('**SALMONELLA** – THE CASE **FOR**')-THE BOFFIN CHICKEN HAS A KEEN '**HANDS ON**' INTEREST IN **ENTOMOLOGY** & LIVES QUIETLY IN RURAL BUCKINGHAMSHIRE ★

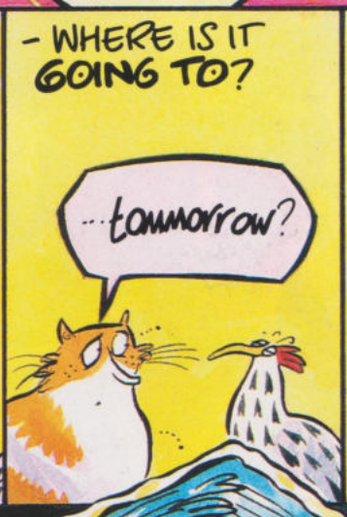
ALEXIS, THE 'QUANTUM' CAT HAS NO **REAL** SCIENTIFIC BACKGROUND, BUT KEEPS A **WATCHING BRIEF** ON FAVOURABLE ADVANCES IN **FAST FOOD** TECHNOLOGY ★ ALWAYS ALERT FOR A NEW **SUSHI** BAR OPENING, THE CREATURE LIVES IN **SQUALOR** IN A JIFFY BAG CUPBOARD, SOMEWHERE IN A SOUTH LONDON RIVERSIDE TOWER BLOCK ★

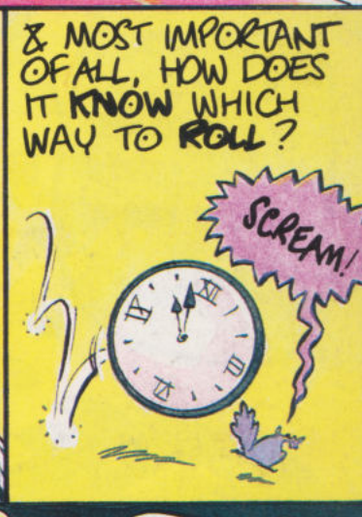
KATE CHARLESWORTH, WHO DREW THE **PICTURES**, DID THE LETTERING & A LOT OF THE JOKES, WAS BORN IN BARNSLEY, TRAINED (SOMETIMES AT ART SCHOOL) IN MANCHESTER & CAME TO LONDON TO BE AN **ILLUSTRATOR** ★ SHE SOON REALISED THAT DOING **CARTOONS** WAS MUCH QUICKER, MORE FUN & PAID THE SAME SORT OF MONEY AS THE **OTHER** STUFF ★ A CAREER MOVE SEEMED **INEVITABLE** ★ SHE HAS WORKED FOR A WILDLY DISPARATE (& **LONG**) LIST OF CLIENTS: HER PREVIOUS BOOK '**ALL THAT**-THE **OTHER** HALF OF HISTORY' WITH MARSAILI CAMERON-(WHICH PROVED THAT WOMEN DID **INDEED** EXIST IN BRITISH HISTORY)-**PROBABLY** HAS NO RELEVANCE TO THIS VOLUME ★ HER CARTOON STRIP, 'LIFE, THE UNIVERSE & (ALMOST) EVERYTHING', WHICH APPEARS IN NEW SCIENTIST MAGAZINE, SOMETIMES **DOES** ★

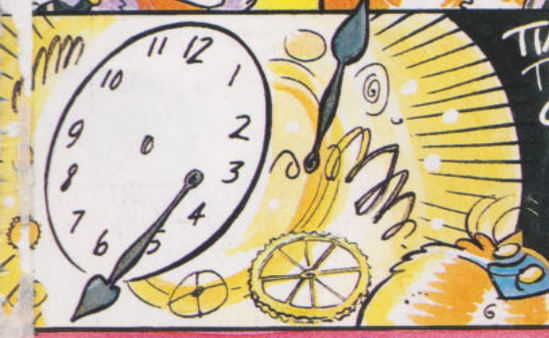
JOHN GRIBBIN OBTAINED HIS PhD IN **ASTROPHYSICS** FROM THE UNIVERSITY OF CAMBRIDGE, WHERE HE WORKED IN A DIFFERENT **BUILDING** FROM STEPHEN **HAWKING** ★ HE MANAGED TO **AVOID** BEING INVOLVED IN THE DISCOVERY OF **PULSARS**, WHICH WAS MADE BY A **THIRD** ASTRONOMY GROUP IN CAMBRIDGE AT THAT TIME, & NOR DID HE MAKE ANY SIGNIFICANT CONTRIBUTION TO THE INVESTIGATION OF **QUASARS** OR THE SEARCH FOR THE MISSING **MASS** ★ DECIDING THAT HE WAS NOT SUFFICIENTLY **PRONE** TO MAKING A CAREER IN RESEARCH HE TURNED INSTEAD TO **WRITING** ABOUT SCIENCE ★ HE HAS NOW PRODUCED **MORE** BOOKS THAN YOU CAN SHAKE A STICK AT, THE MOST RELEVANT TO THE VOLUME YOU NOW HOLD BEING 'IN SEARCH OF **SCHRÖDINGER'S CAT**' (ABOUT QUANTUM PHYSICS & REALITY) & 'IN SEARCH OF THE **BIG BANG**' (ABOUT THE ORIGIN & EVOLUTION OF THE UNIVERSE) ★ AS WELL AS WRITING ABOUT SCIENCE THAT SOUNDS AS IF IT IS SCIENCE **FICTION**, HE ALSO WRITES SCIENCE FICTION **NOVELS** IN WHICH **ALL** THE SCIENCE IS BASED ON **FACT** ★ HE IS RESPONSIBLE FOR THE **WORDS** IN THIS BOOK, & SWEARS ON EINSTEIN'S **SOCKS** THAT EVERY ONE IS **TRUE** ★

What is TIME?









TIME IS REALLY ABOUT THINGS WEARING OUT...!

'Time, like an ever-rolling stream...'

THIS FACT IS SO IMPORTANT, IT IS ENSHRINED IN SCIENCE AS THE 2ND LAW OF THERMODYNAMICS. SO IMPORTANT, THAT ARTHUR EDDINGTON, A GREAT SCIENTIST OF THE 1920s, DESCRIBED IT AS:

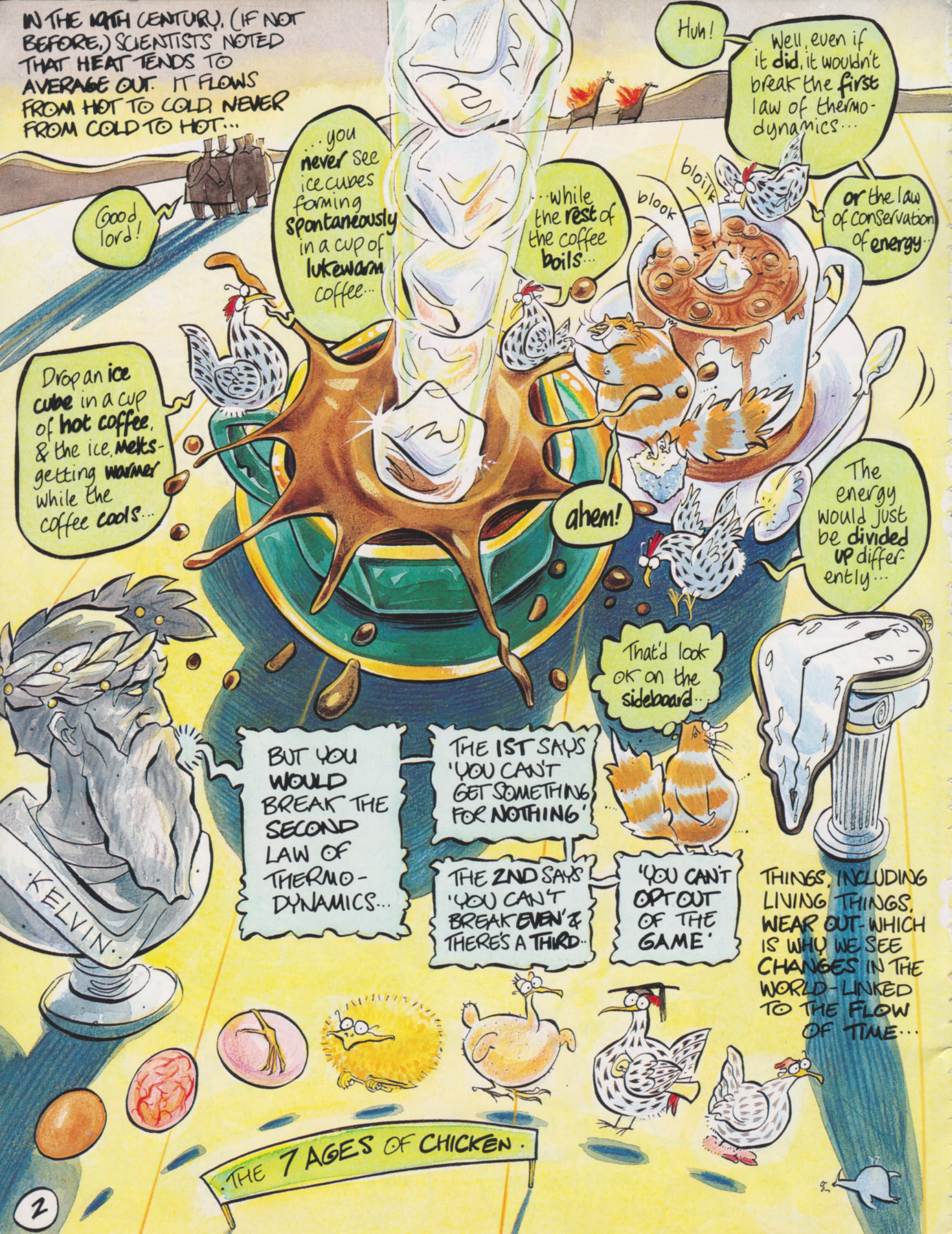
'THE SUPREME LAW OF NATURE'

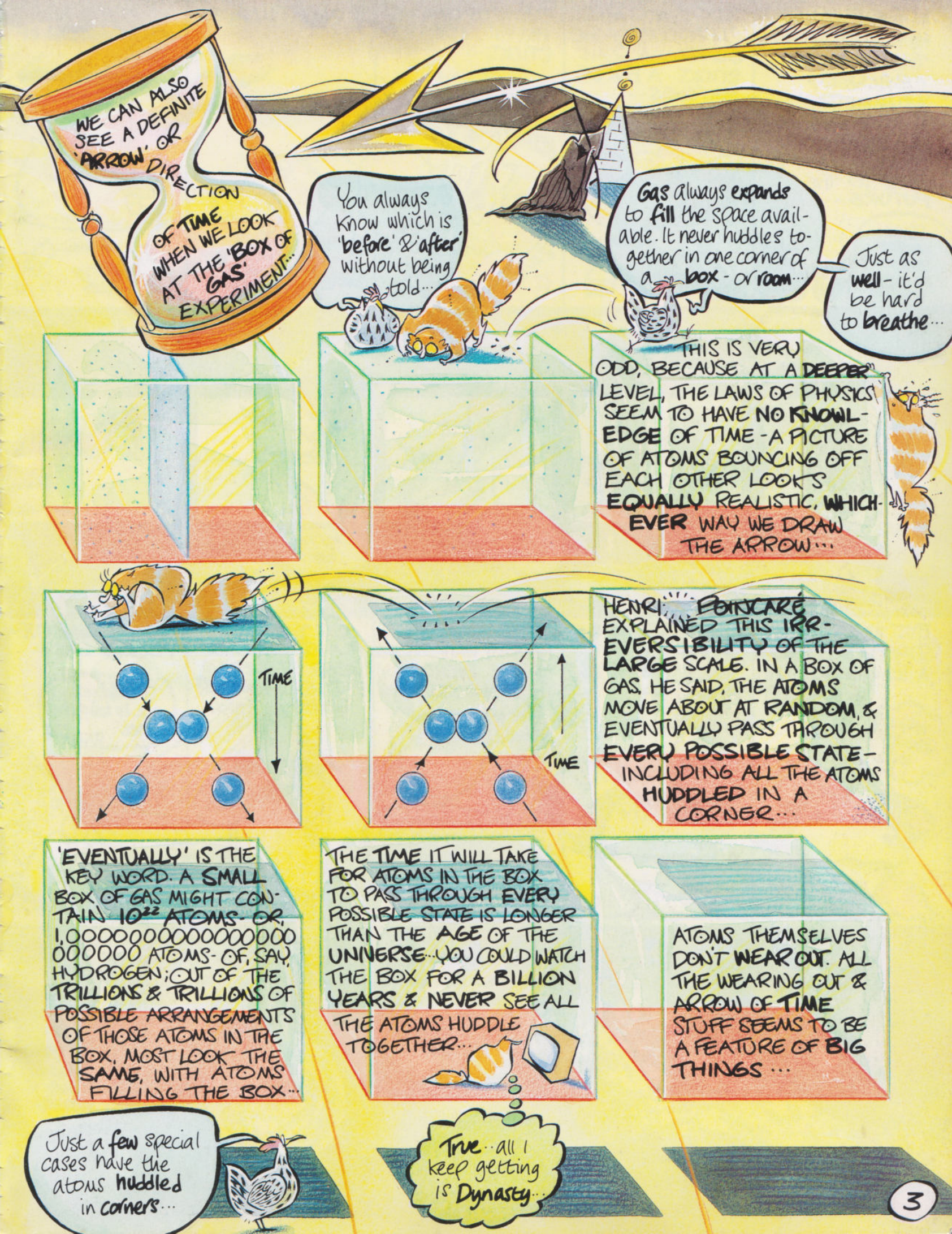
What makes it the 2nd law, then?

Well, the 1st's a kind of preamble - saying that heat is a form of work...

'Heat is work & work is heat...'

I like it...


IN THE 19TH CENTURY, (IF NOT BEFORE,) SCIENTISTS NOTED THAT HEAT TENDS TO AVERAGE OUT. IT FLOWS FROM HOT TO COLD, NEVER FROM COLD TO HOT...
Good lord!
...you never see ice cubes forming spontaneously in a cup of lukewarm coffee...
...while the rest of the coffee boils...
Huh!
Well, even if it did, it wouldn't break the first law of thermo-dynamics...
or the law of conservation of energy...
blook
bloilk
Drop an ice cube in a cup of hot coffee, & the ice melts - getting warmer while the coffee cools...
ahem!
The energy would just be divided up differ-ently...
That'd look OK on the sideboard...
BUT YOU WOULD BREAK THE SECOND LAW OF THERMO-DYNAMICS...
THE 1ST SAYS 'YOU CAN'T GET SOMETHING FOR NOTHING'
THE 2ND SAYS 'YOU CAN'T BREAK EVEN' & THERE'S A THIRD...
'YOU CAN'T OPT OUT OF THE GAME'
KELVIN.
THINGS, INCLUDING LIVING THINGS, WEAR OUT - WHICH IS WHY WE SEE CHANGES IN THE WORLD - LINKED TO THE FLOW OF TIME...
THE 7 AGES OF CHICKEN.
2


WE CAN ALSO SEE A DEFINITE 'ARROW' OR DIRECTION OF TIME WHEN WE LOOK AT THE 'BOX OF GAS' EXPERIMENT...
You always know which is 'before' & 'after' without being told...
Gas always expands to fill the space available. It never huddles together in one corner of a box - or room...
Just as well - it'd be hard to breathe...
THIS IS VERY ODD, BECAUSE AT A DEEPER LEVEL, THE LAWS OF PHYSICS SEEM TO HAVE NO KNOWLEDGE OF TIME - A PICTURE OF ATOMS BOUNCING OFF EACH OTHER LOOKS EQUALLY REALISTIC, WHICHEVER WAY WE DRAW THE ARROW...
TIME
TIME
HENRI POINCARÉ EXPLAINED THIS IRREVERSIBILITY OF THE LARGE SCALE. IN A BOX OF GAS, HE SAID, THE ATOMS MOVE ABOUT AT RANDOM, & EVENTUALLY PASS THROUGH EVERY POSSIBLE STATE - INCLUDING ALL THE ATOMS HUDDLED IN A CORNER...
'EVENTUALLY' IS THE KEY WORD. A SMALL BOX OF GAS MIGHT CONTAIN 10^{22} ATOMS - OR, 1,000000000000000000000 ATOMS - OF, SAY, HYDROGEN; OUT OF THE TRILLIONS & TRILLIONS OF POSSIBLE ARRANGEMENTS OF THOSE ATOMS IN THE BOX, MOST LOOK THE SAME, WITH ATOMS FILLING THE BOX...
THE TIME IT WILL TAKE FOR ATOMS IN THE BOX TO PASS THROUGH EVERY POSSIBLE STATE IS LONGER THAN THE AGE OF THE UNIVERSE... YOU COULD WATCH THE BOX FOR A BILLION YEARS & NEVER SEE ALL THE ATOMS HUDDLE TOGETHER...
ATOMS THEMSELVES DON'T WEAR OUT. ALL THE WEARING OUT & ARROW OF TIME STUFF SEEMS TO BE A FEATURE OF BIG THINGS...
Just a few special cases have the atoms huddled in corners...
True... all I keep getting is Dynasty...

IN THE **EVERYDAY** WORLD, EVEN THINGS THAT ARE NOT OBVIOUSLY **'ASYMMETRIC'** IN TIME ARE REALLY **MOVING** IN A CLEAR FASHION FROM THE **PAST** TO THE **FUTURE**...

Yeah. **Imagine** somebody making a **bonfire**...

START WITH A NICE, CLEAN COPY OF THE **GUARDIAN**... SOME **STICKS**... A BOX OF **MATCHES**...

CRUMPLE UP THE PAPER, ADD STICKS...

KRUNCH!

RAVAGE!

THEN APPLY **MATCH**

THERE IS AN INBUILT **ARROW** OF **TIME**...

SCREAM!

IF WE MADE A **MOVIE** OF THE SCENE & RAN IT **BACKWARDS**

...**love** this bit...

-WE WOULD **KNOW** IT WAS WRONG...

You **should** have used the **sun**...

WE COULD **EVEN** MAKE A MOVIE, CUT IT UP INTO INDIVIDUAL **FRAMES**...

cruelty to dumb **animals**!

& STILL, WITH SOME CARE, PUT IT **BACK TOGETHER** AGAIN...

har har har!

THE **FLOW** OF **TIME** IS CLEAR.

skrawk!

BUT WHAT ABOUT SOMEBODY **BOUNCING** A TENNIS BALL WITH A **RACKET**?

What about it?

ALEXIS

FILM **THAT** & RUN IT BACKWARDS, & IT **LOOKS** PERFECTLY **NATURAL**...

?it about what

ALEXIS

THE REASON IS, WE HAVEN'T WAITED **LONG** ENOUGH. EVENTUALLY, THE **BALL** WILL **WEAR** OUT.

or go **bald**...

OR THE TENNIS PLAYER WILL DROP **DEAD**, OR NEED TO **EAT**, OR **DRINK**-OR **SOME**- THING.

Sigh...

THINGS **WEAR** OUT- PEOPLE **DIE**...

I **told** you not to **leap** the **net**...

HOWEVER, ON THE VERY **BIG** SCALE, A FILM OF **THIS** LOOKS THE **SAME**- FOREWARDS **OR** BACKWARDS.

BUT AGAIN, **ONLY** BECAUSE WE HAVEN'T WAITED **LONG** ENOUGH...

TIDAL FORCES SLOWLY CHANGE THE **ORBITS** OF THE PLANETS...

THE EARTH WILL ROTATE MORE **SLOWLY** - AS A RESULT, THE MOON MOVES FURTHER **AWAY**...

Someone isn't using... **GRAVITY**!

THE DAYS DWINDLE DOWN TO A PRECIOUS FEW. BUT EACH ONE IS **WEEKS LONG**...

The Rockies have crumbled... Gibraltar has tumbled...

We're going to have to work out a **different system** for birthdays...

WALL ST

YOU CAN **WATCH** A PILE OF **BRICKS** & A CEMENT MIXER FOR **EVER**...'

SWAMI CHICKEN IS **IN**

'BUT THEY WILL **NEVER** TURN INTO A **HOUSE**...'

'WATCH A **HOUSE** FOR **EVER**...

PING!

'& IT WILL **CRUMBLE** INTO A PILE OF **BRICKS**...'

THINGS GET MORE **DISORDERED** AS TIME PASSES...

BUT A '**FILM**' DOESN'T HAVE TO 'RUN' IN A **PROJECTOR** FOR THE DIRECTION OF TIME TO BE **CLEAR**.

Yean-**half an hour**, & the projector's **still** not been fixed...

MAYBE TIME IS IN SOME SENSE **FROZEN** LIKE THIS...

'**Life is**– just waiting for your **projector** to be fixed...'

SO THAT **ALL** TIME EXISTS AT THE **SAME** TIME...

How can my **personal film** be showing itself **all** at the **same time**?

...& ONLY **OUR PERCEPTION** OF SUCCESSIVE **BITS** OF TIME **ACTUALLY** MOVES FORWARD...

Look! **Proof**! That wasn't there **before**!

...LIKE SEEING SUCCESSIVE FRAMES OF **FILM**...

...& I've seen this one before...

The **best** proof is **edible** proof...

THE ARROW OF TIME IS A **FUNDAMENTAL FEATURE**, POINTING FROM PAST TO FUTURE...

THE FLOW OF TIME MAY BE A **SUBJECTIVE** PHENOMENON...

IF TIME FLOWED **BACKWARDS**, IT WOULD MAKE **NO** DIFFERENCE TO THE **ASYMMETRY**...

& **ALL** THE THERMO-DYNAMIC DISCUSSION WOULD STILL STAND.

WHICH MAKES IT ALL THE MORE **PECULIAR** THAT **ATOMS** & **SUB-ATOMIC PARTICLES** DON'T SEEM TO **KNOW** ABOUT THE ARROW AT ALL...

NOBEL PRIZEWINNER ILYA PRIGOGINE HAS A NEW THEORY OF TIME. HE SAYS THAT MICROSCOPIC SYSTEMS ARE JUST AS REVERSIBLE AS MACROSCOPIC SYSTEMS...

...WITH AN INBUILT ARROW OF TIME... HE BASES HIS IDEA ON A COMBINATION OF THERMODYNAMICS & QUANTUM THEORY...

WHKRRR

could I forget?

Wait for it!

REMEMBER THE BOX OF GAS WITH ATOMS FLYING ABOUT & BOUNCING OFF EACH OTHER? OR...

NEWTON'S LAWS SAY THAT EACH OF THESE COLLISIONS STILL OBEYS THE LAWS OF PHYSICS. IF IT IS REVERSED - WHICH MEANS THE WHOLE BOX OF GAS IS 'TIME REVERSIBLE' WHICH MEANS THAT IF, BY MAGIC, THE MOTION OF EVERY ATOM IN THE GAS BOX COULD BE REVERSED...

...IT'S BEHAVIOUR WOULD STILL SATISFY THE NEWTONIAN LAWS...

SINCE THE 19TH CENTURY, PHYSICISTS HAVE PUZZLED HOW A WORLD BUILT OUT OF TIME REVERSIBLE ATOMS CAN BE IRREVERSIBLE ON THE LARGE SCALE. BUT PRIGOGINE SAYS THESE ATOMS ARE NOT TIME REVERSIBLE.

Think about how we glibly say 'reverse the motion of every atom simultaneously...'

we do?

To understand, we need to know exactly where every atom is...

...& exactly where, & how fast, it's going - it's position & momentum...

RRRRrip

But Quantum physics says this is impossible!

THE EQUATIONS OF QUANTUM PHYSICS ARE THEMSELVES REVERSIBLE - THEY HAVE NO ARROW OF TIME BUILT INTO THEM, ANY MORE THAN NEWTON'S EQUATIONS HAVE. BUT QUANTUM PHYSICS HAVE A NEW FEATURE - DISCOVERED BY WERNER HEISENBERG.

HEISENBERG PROVED THAT IT IS IMPOSSIBLE TO KNOW, AT SUB-ATOMIC LEVELS...

POCK!

EXACTLY WHERE A PARTICLE IS, & WHERE IT'S GOING...

THIS IS KNOWN AS HEISENBERG'S UNCERTAINTY PRINCIPLE...

PLOP

PLUNK!

The IRREVERSIBILITY SHOW!

& TO CONTINUE...

WE CAN DETERMINE EITHER PROPERTY AS ACCURATELY AS WE LIKE-

-WERNER?

er... Ja!

WERNER HEISENBERG · PHYSICIST

BUT THE BETTER WE KNOW ONE, THE LESS INFORMATION WE HAVE ABOUT THE OTHER...

-JUNIOR CHICKEN?

JUNIOR CHICKEN · BOFFIN

get on with it...

NOT 'JUST A THEORY!' WERNER'S PRINCIPLE IS THE FOUNDATION STONE OF QUANTUM PHYSICS-

RIGHT, ALEXIS?

ALEXIS · QUANTUM CAT · FOOL

gulp..

& QUANTUM PHYSICS, AS WE ALL KNOW, EXPLAINS EVERY-THING FROM DNA & LASERS TO MOI INVAD-ING YOUR SCREEN!

SO! SOME PEOPLE THINK THIS IS BECAUSE THE ACT OF MEASUR-ING THE OBJECT DISTURBS IT'-

ALEXIS?

Well, that's true for my inside leg...

True but irrelevant! & that goes for quantum measure-ment!

HEISENBERG SHOWED THAT AN OBJECT LIKE AN ELECTRON DOES NOT POSSESS BOTH MOMENTUM & POSITION SIMUL-TANEOUSLY. THEY ARE BOTH PROPER-TIES KNOWN AS CONJUGATE VARIABLES, & THE QUANTITY THE OBJECT POSSESSES IS A DEFINITE AMOUNT OF—

-ALEXIS?

um... erm...

RIGHT!

UNCERTAINTY!

In effect, a product of the 2 variables. This is an intrinsic uncertainty which has to do with how the Universe is put together...

HARDLY COMMONSENSE, WERNER!

Why should it be? Our commonsense is not based on experience of tiny particles, but on huge collections of particles...

-WERNER?

WERNER GETTING A BIT DEFENSIVE, THERE!

SO WHEN WE SAY 'RELEASE THE ATOMS IN THE BOX' - REWIND THE TAPE - ARE WE ASKING THE IMPOSSIBLE?

Impossible?! It's against the laws of nature! Nothing is powerful enough!

To reverse motion, we would first have to know the position & momen-tum of each particle—

-& this is not permitted!

Even a box of gas - the ideal example of thermo-dynamics at work - is not really reversible!

Even the collision between 2 single atoms is not perfectly reversible - This is a fundamental of nature!

JUST GREAT, WERNER...

'Irreversibility', says Prigogine triumphantly, 'is either true on all levels or none. It cannot emerge as if by a miracle, by going from one level to another...'

-& THAT HOLDS EVEN WHEN WE GO TO THE HIGH-EST LEVEL OF ALL-

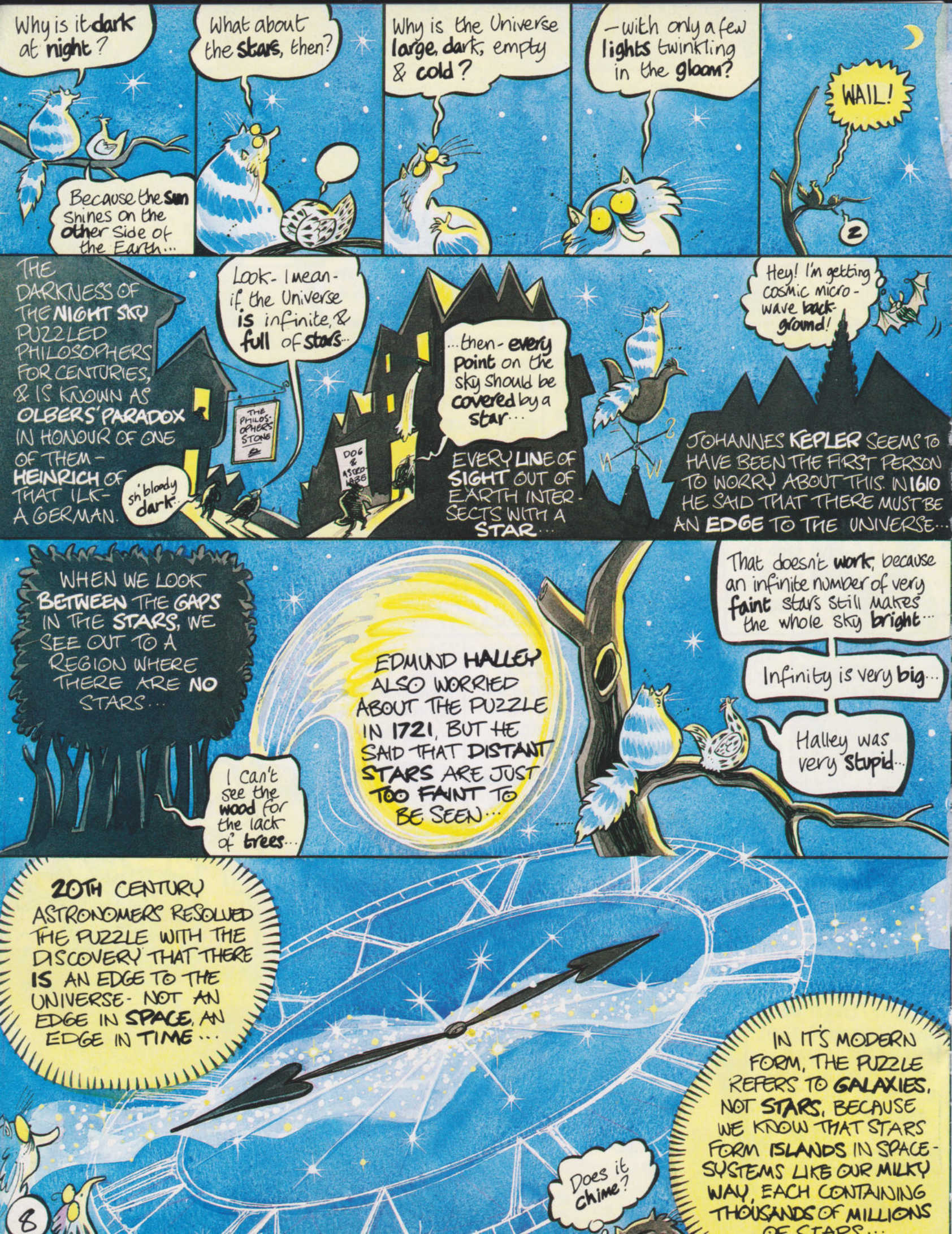
-WERNER VON HEISENBERG, YOU HAVE WON TONIGHT'S STAR PRIZE...

THE UNIVERSE!!

ER-RIGHT!

THE IRREVERSIBILITY SHOW

WOOOOOOOO!


Why is it dark at night?
Because the sun shines on the other side of the Earth...
What about the stars, then?
Why is the Universe large, dark, empty & cold?
—with only a few lights twinkling in the gloom?
WAIL!
2
THE DARKNESS OF THE NIGHT SKY PUZZLED PHILOSOPHERS FOR CENTURIES, & IS KNOWN AS OLBERS' PARADOX IN HONOUR OF ONE OF THEM - HEINRICH OF THAT ILK - A GERMAN.
sh'bloody dark...
Look - I mean - if the Universe is infinite, & full of stars...
THE PHILOSOPHERS STONE
DOG & PISTOL 1836
...then - every point on the sky should be covered by a star...
EVERY LINE OF SIGHT OUT OF EARTH INTERSECTS WITH A STAR...
Hey! I'm getting cosmic micro-wave background!
JOHANNES KEPLER SEEMS TO HAVE BEEN THE FIRST PERSON TO WORRY ABOUT THIS. IN 1610 HE SAID THAT THERE MUST BE AN EDGE TO THE UNIVERSE...
WHEN WE LOOK BETWEEN THE GAPS IN THE STARS, WE SEE OUT TO A REGION WHERE THERE ARE NO STARS...
I can't see the wood for the lack of trees...
EDMUND HALLEY ALSO WORRIED ABOUT THE PUZZLE IN 1721, BUT HE SAID THAT DISTANT STARS ARE JUST TOO FAINT TO BE SEEN...
That doesn't work, because an infinite number of very faint stars still makes the whole sky bright...
Infinity is very big...
Halley was very stupid...
20TH CENTURY ASTRONOMERS RESOLVED THE PUZZLE WITH THE DISCOVERY THAT THERE IS AN EDGE TO THE UNIVERSE - NOT AN EDGE IN SPACE, AN EDGE IN TIME...
IN IT'S MODERN FORM, THE PUZZLE REFERS TO GALAXIES, NOT STARS, BECAUSE WE KNOW THAT STARS FORM ISLANDS IN SPACE - SYSTEMS LIKE OUR MILKY WAY, EACH CONTAINING THOUSANDS OF MILLIONS
Does it chime?
8

BUT THE PUZZLE IS THE **SAME** - WHEN WE LOOK OUT THROUGH THE GAPS IN THE GALAXIES, WE SHOULD SEE **MORE** GALAXIES, & **SO** ON & **SO** ON...

I feel a bit **faint**...

This is the sort of thing I **lie awake** & **worry** about...

...If you do the calculation **properly**, it turns **out** that **if** the Universe is **infinite** & **unchanging**, then the **whole sky** should be as bright as the **sun**...

...basically, because every line of **sight** ends on the surface of a **star**...

Well, why **isn't** it?

Look - just tell me something **comforting**...

The key word is '**un-changing**'

LIGHT TAKES A **FINITE** TIME TO CROSS **SPACE**; THE DISTANCE TRAVELLED IN **1 YEAR** IS CALLED A **LIGHT YEAR** (A MEASURE OF DISTANCE, NOT OF **TIME**...)

Yes...

If there were **no stars** in existence before, say, **50000** years ago...

yes

...then **no light** from **any** region of the Universe **more** than 50000 light years away...

...can have **reached** us yet!

That's **it**?!

IT WAS SURPRISING THAT **HALLEY** & HIS CONTEMPORARIES (INCLUDING **NEWTON**) HADN'T HIT ON THIS RESOLUTION OF THE PUZZLE. THE **FINITE SPEED** OF **LIGHT** HAD BEEN CALCULATED IN **1676** BY **OLE ROEMER**, A **DANE**...

1676

'There is nothing like a **Dane**...'

...FROM STUDIES OF ECLIPSES OF THE MOONS OF **JUPITER**

?

Newton mentioned it in his **Opticks**...

Drunk, eh?

Published in 1704

At the time, the **Church** taught that the Universe had been created in **4004 BC**...

What about **fossils**, then?

IF SO, THEN **NO LIGHT** FROM ANY OBJECT MORE THAN **5725** LIGHT YEARS AWAY COULD HAVE **REACHED** EARTH AT THE TIME HALLEY DISCUSSED THE PUZZLE AT THE **ROYAL SOCIETY** IN **1721**. WHICH WOULD HAVE **SOLVED** IT NICELY...

HE **COULD** HAVE SAID THAT THE DARKNESS OF THE NIGHT SKY WAS CIRCUMSTANTIAL **EVIDENCE** FOR THE **NATURE** OF **GOD**...

Sod **off**! Some of us have gotta **hunt**!

THE FACT THAT HE **DIDN'T** MIGHT SHOW HOW MUCH FAITH HE HAD IN THE **OFFICIAL DATE** FOR THE **CREATION**...

Some thought there was **more than one** Creation - God got it right with **this** one...

WE **NOW** KNOW THAT THE UNIVERSE IS **EXPANDING**... GALAXIES **MOVE APART** AS TIME PASSES...

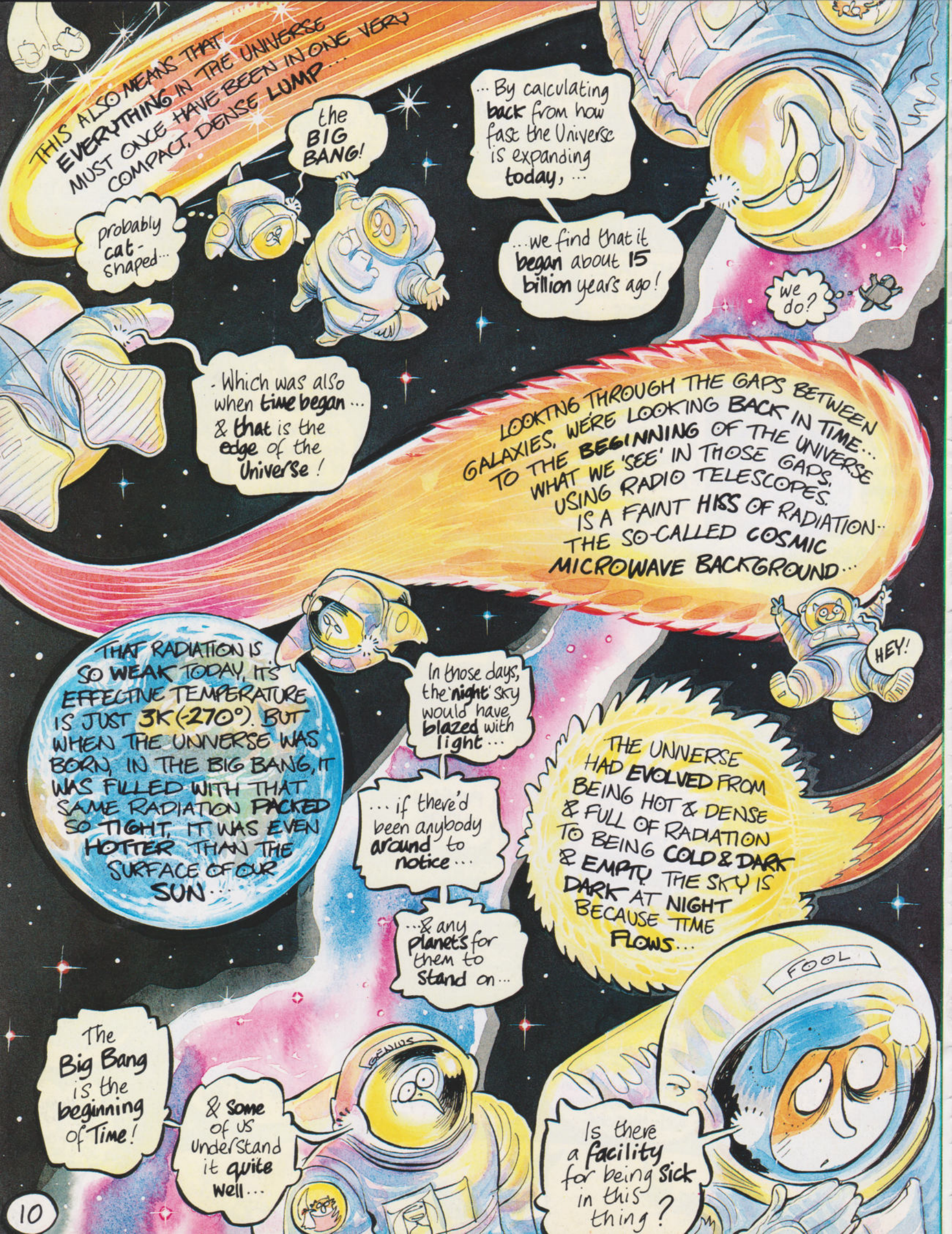
& **junked** the first attempts - hence, **fossils**!

ANOTHER MEASURE OF THE ARROW OF TIME, THE **PAST** IS WHEN GALAXIES WERE CLOSER **TOGETHER**...

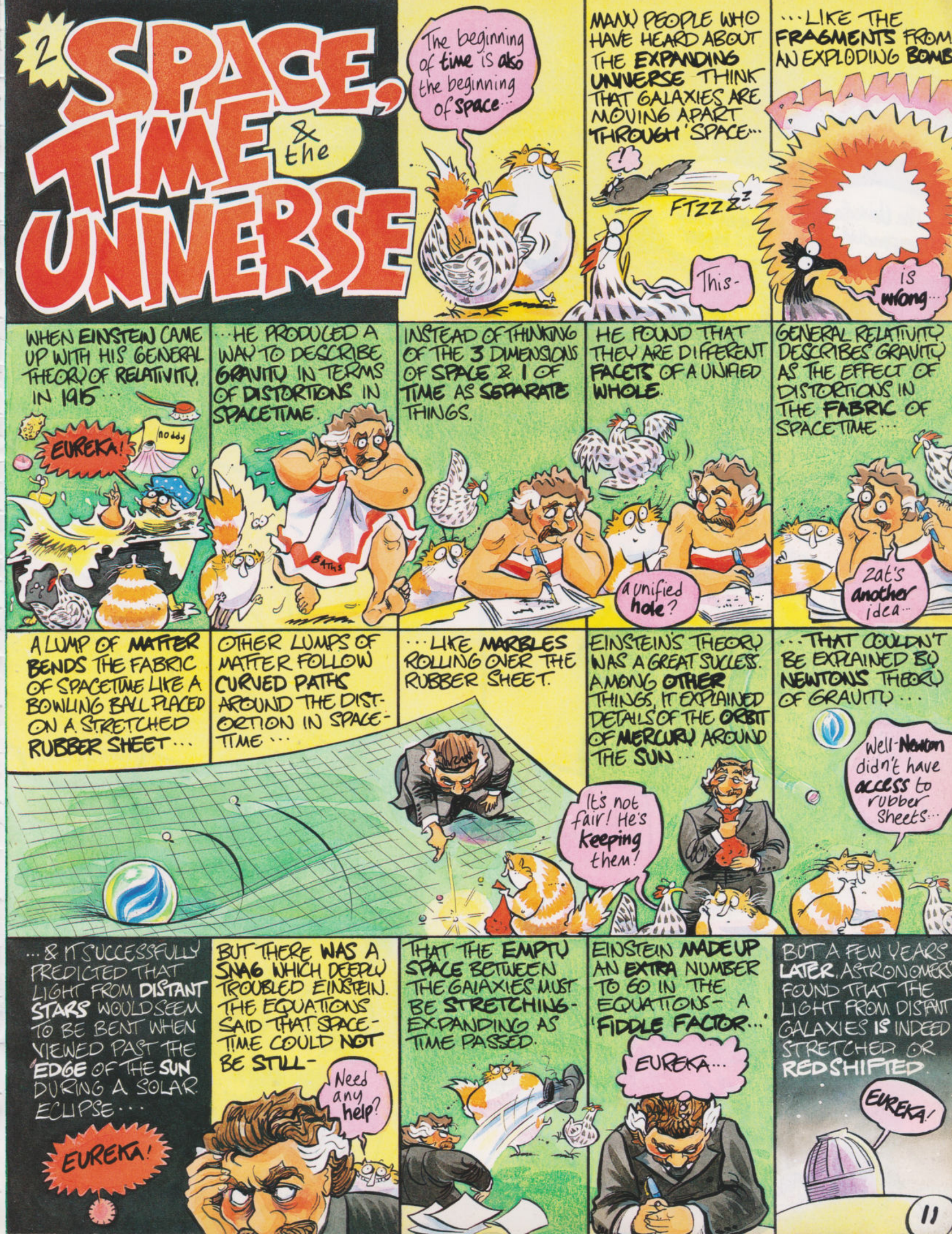
Another lot thought fossils were the **original moulds** he'd used

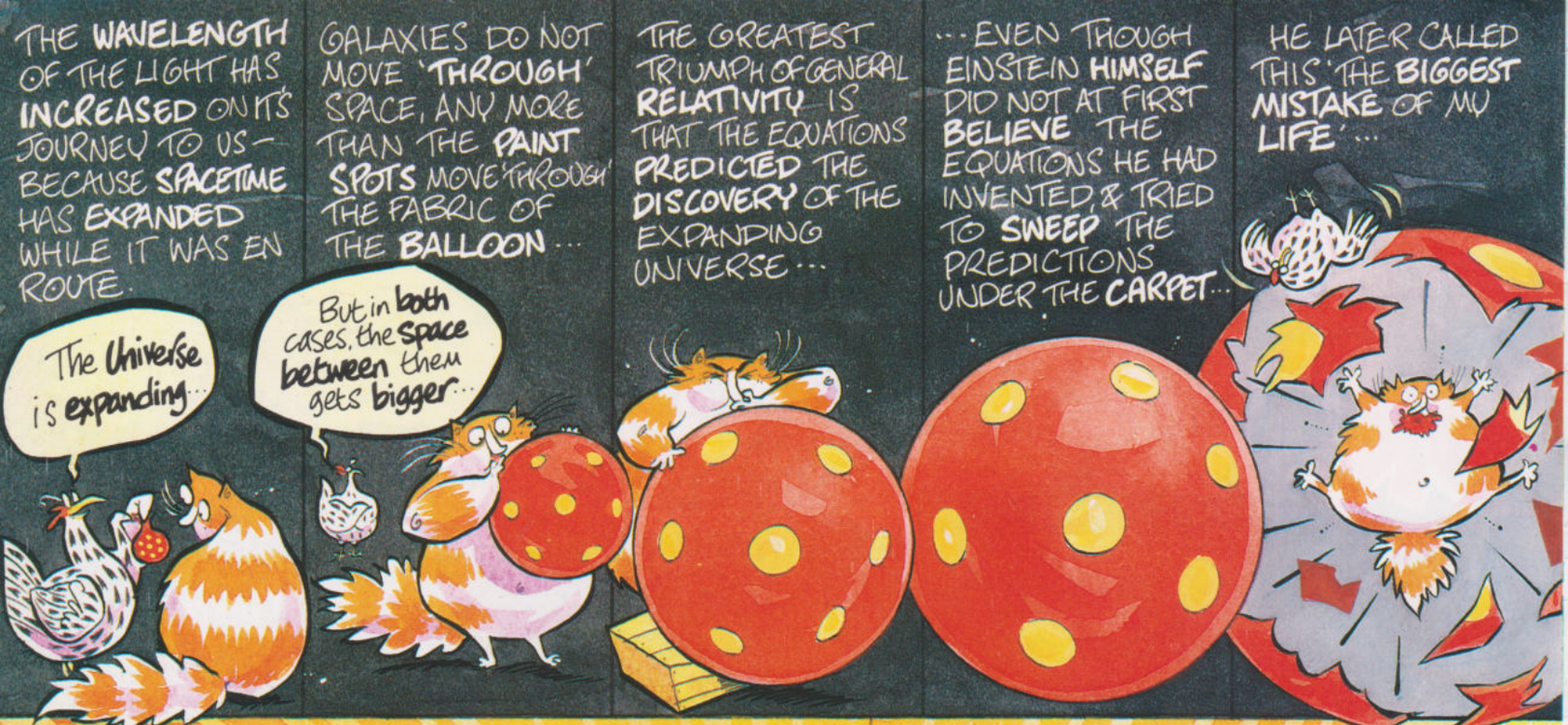
THE **FUTURE** IS WHEN THEY'RE FURTHER **APART**.

I always thought they were from some sort of **theme park**...


THIS ALSO MEANS THAT EVERYTHING IN THE UNIVERSE MUST ONCE HAVE BEEN IN ONE VERY COMPACT, DENSE LUMP...
the BIG BANG!
probably cat-shaped...
...By calculating back from how fast the Universe is expanding today, ...
...we find that it began about 15 billion years ago!
we do?
- Which was also when time began... & that is the edge of the Universe!
LOOKING THROUGH THE GAPS BETWEEN GALAXIES, WE'RE LOOKING BACK IN TIME... TO THE BEGINNING OF THE UNIVERSE WHAT WE 'SEE' IN THOSE GAPS, USING RADIO TELESCOPES, IS A FAINT HISS OF RADIATION.. THE SO-CALLED COSMIC MICROWAVE BACKGROUND...
HEY!
THAT RADIATION IS SO WEAK TODAY, IT'S EFFECTIVE TEMPERATURE IS JUST 3K (-270°). BUT WHEN THE UNIVERSE WAS BORN, IN THE BIG BANG, IT WAS FILLED WITH THAT SAME RADIATION PACKED SO TIGHT, IT WAS EVEN HOTTER THAN THE SURFACE OF OUR SUN...
In those days, the 'night' sky would have blazed with light...
...if there'd been anybody around to notice...
...& any planets for them to stand on...
THE UNIVERSE HAD EVOLVED FROM BEING HOT & DENSE & FULL OF RADIATION TO BEING COLD & DARK & EMPTY. THE SKY IS DARK AT NIGHT BECAUSE TIME FLOWS...
The Big Bang is the beginning of Time!
GENIUS
& some of us understand it quite well...
FOOL
Is there a facility for being sick in this thing?

2 SPACE, TIME & the UNIVERSE


The beginning of time is also the beginning of space...
MANY PEOPLE WHO HAVE HEARD ABOUT THE EXPANDING UNIVERSE THINK THAT GALAXIES ARE MOVING APART THROUGH SPACE...
FTzzzz
This-
...LIKE THE FRAGMENTS FROM AN EXPLODING BOMB
is wrong...
WHEN EINSTEIN CAME UP WITH HIS GENERAL THEORY OF RELATIVITY, IN 1915...
EUREKA!
noddy
...HE PRODUCED A WAY TO DESCRIBE GRAVITY IN TERMS OF DISTORTIONS IN SPACETIME.
BATHS
INSTEAD OF THINKING OF THE 3 DIMENSIONS OF SPACE & 1 OF TIME AS SEPARATE THINGS,
HE FOUND THAT THEY ARE DIFFERENT FACETS OF A UNIFIED WHOLE.
a unified hole?
GENERAL RELATIVITY DESCRIBES GRAVITY AS THE EFFECT OF DISTORTIONS IN THE FABRIC OF SPACETIME...
zat's another idea...
A LUMP OF MATTER BENDS THE FABRIC OF SPACETIME LIKE A BOWLING BALL PLACED ON A STRETCHED RUBBER SHEET...
OTHER LUMPS OF MATTER FOLLOW CURVED PATHS AROUND THE DISTORTION IN SPACETIME...
...LIKE MARBLES ROLLING OVER THE RUBBER SHEET.
EINSTEIN'S THEORY WAS A GREAT SUCCESS. AMONG OTHER THINGS, IT EXPLAINED DETAILS OF THE ORBIT OF MERCURY AROUND THE SUN...
It's not fair! He's keeping them!
...THAT COULDN'T BE EXPLAINED BY NEWTON'S THEORY OF GRAVITY...
Well-Newton didn't have access to rubber sheets...
...& IT SUCCESSFULLY PREDICTED THAT LIGHT FROM DISTANT STARS WOULD SEEM TO BE BENT WHEN VIEWED PAST THE EDGE OF THE SUN DURING A SOLAR ECLIPSE...
EUREKA!
BUT THERE WAS A SNAG WHICH DEEPLY TROUBLED EINSTEIN. THE EQUATIONS SAID THAT SPACETIME COULD NOT BE STILL-
Need any help?
THAT THE EMPTY SPACE BETWEEN THE GALAXIES MUST BE STRETCHING-EXPANDING AS TIME PASSED.
EINSTEIN MADE UP AN EXTRA NUMBER TO GO IN THE EQUATIONS- A 'FIDDLE FACTOR'...
EUREKA...
BUT A FEW YEARS LATER, ASTRONOMERS FOUND THAT THE LIGHT FROM DISTANT GALAXIES IS INDEED STRETCHED OR REDSHIFTED.
EUREKA!


THE WAVELENGTH OF THE LIGHT HAS INCREASED ON ITS JOURNEY TO US – BECAUSE SPACETIME HAS EXPANDED WHILE IT WAS EN ROUTE.
GALAXIES DO NOT MOVE 'THROUGH' SPACE, ANY MORE THAN THE PAINT SPOTS MOVE 'THROUGH' THE FABRIC OF THE BALLOON...
THE GREATEST TRIUMPH OF GENERAL RELATIVITY IS THAT THE EQUATIONS PREDICTED THE DISCOVERY OF THE EXPANDING UNIVERSE...
...EVEN THOUGH EINSTEIN HIMSELF DID NOT AT FIRST BELIEVE THE EQUATIONS HE HAD INVENTED, & TRIED TO SWEEP THE PREDICTIONS UNDER THE CARPET...
HE LATER CALLED THIS 'THE BIGGEST MISTAKE OF MY LIFE'...
The Universe is expanding...
But in both cases, the space between them gets bigger...

BANG
The BIG BANG was the beginning of TIME!
We look out into the Universe...
...& see that the galaxies are moving apart as space time expands...
We do?
Do they?

BY 'RUNNING THE MOVIE BACKWARDS' WE CAN SEE THAT EVERYTHING STARTED OUT IN A SUPERDENSE, SUPERHOT FIREBALL 15 BILLION YEARS AGO...
TAKING THIS LITERALLY (& USING EINSTEIN'S GENERAL THEORY OF RELATIVITY) 15 BILLION YEARS AGO, THE UNIVERSE WAS IN A STATE OF INFINITE DENSITY & TEMPERATURE...
EVERYTHING WAS PULLED TOGETHER IN A SINGLE MATHEMATICAL POINT, CALLED A SINGULARITY. BUT SCIENTISTS DON'T LIKE THEORIES THAT HAVE GOT INFINITY IN THEM...
Who does?
Well, I think it's just too big a concept to be comfortable with...
They say that our understanding of physics breaks down if we try to push back to the moment of creation itself...
Downhill all the way!
PHYSICS CAN REALLY ONLY TELL US HOW THE UNIVERSE GOT TO BE THE WAY IT IS. STARTING OUT FROM THE CONDITIONS THAT EXISTED A SPLIT SECOND AFTER THE MOMENT WHEN EVERYTHING WAS PILED TOGETHER IN ONE POINT, AT A TIME WHEN DENSITY & TEMPERATURE WERE ONLY NEARLY INFINITE...
It's-the BEGINNING OF TIME!
-That's as far back as our knowledge can ever go!

TO GIVE EINSTEIN HIS DUE, HIS FAILURE TO BELIEVE HIS OWN EQUATIONS WASN'T REALLY **SUCH** A BIG BLUNDER- IN **1915**, NOBODY KNEW THAT **OTHER** GALAXIES EXISTED...

THEY THOUGHT THAT THE UNIVERSE CONSISTED ONLY OF THE COLLECTION OF **STARS** THAT WE NOW CALL THE **MILKY WAY GALAXY**...

..& **OUR** GALAXY ITSELF IS CERTAINLY **NOT** EXPANDING, BECAUSE ON SUCH A **SMALL** SCALE AS AN **INDIVIDUAL GALAXY**, THE **GRAVITY** OF ALL THE STARS HOLDS THE CLUSTER TOGETHER.

WHAT DO WE MEAN BY **SMALL**? THE MILKY WAY GALAXY IN WHICH THE SUN IS AN **AVERAGE** SORT OF STAR, CONTAINS ABOUT **100 BILLION** STARS...

--MOSTLY SPREAD OVER A **DISC** SOME **100000** LIGHT YEARS IN **DIAMETER** & **2000** LIGHT YEARS **THICK**, WITH OTHER STARS FILLING A SPHERICAL **HALO** **500000** LIGHT YEARS AROUND THE DISC..

(A LIGHT YEAR IS A MEASURE OF **DISTANCE**. NOT TIME - IT'S THE DISTANCE LIGHT TRAVELS IN ONE YEAR. LIGHT TRAVELS AT **300,000 KM** A **SECOND**. A LIGHT YEAR IS A **LONG** WAY - NEARLY TEN THOUSAND BILLION KM)

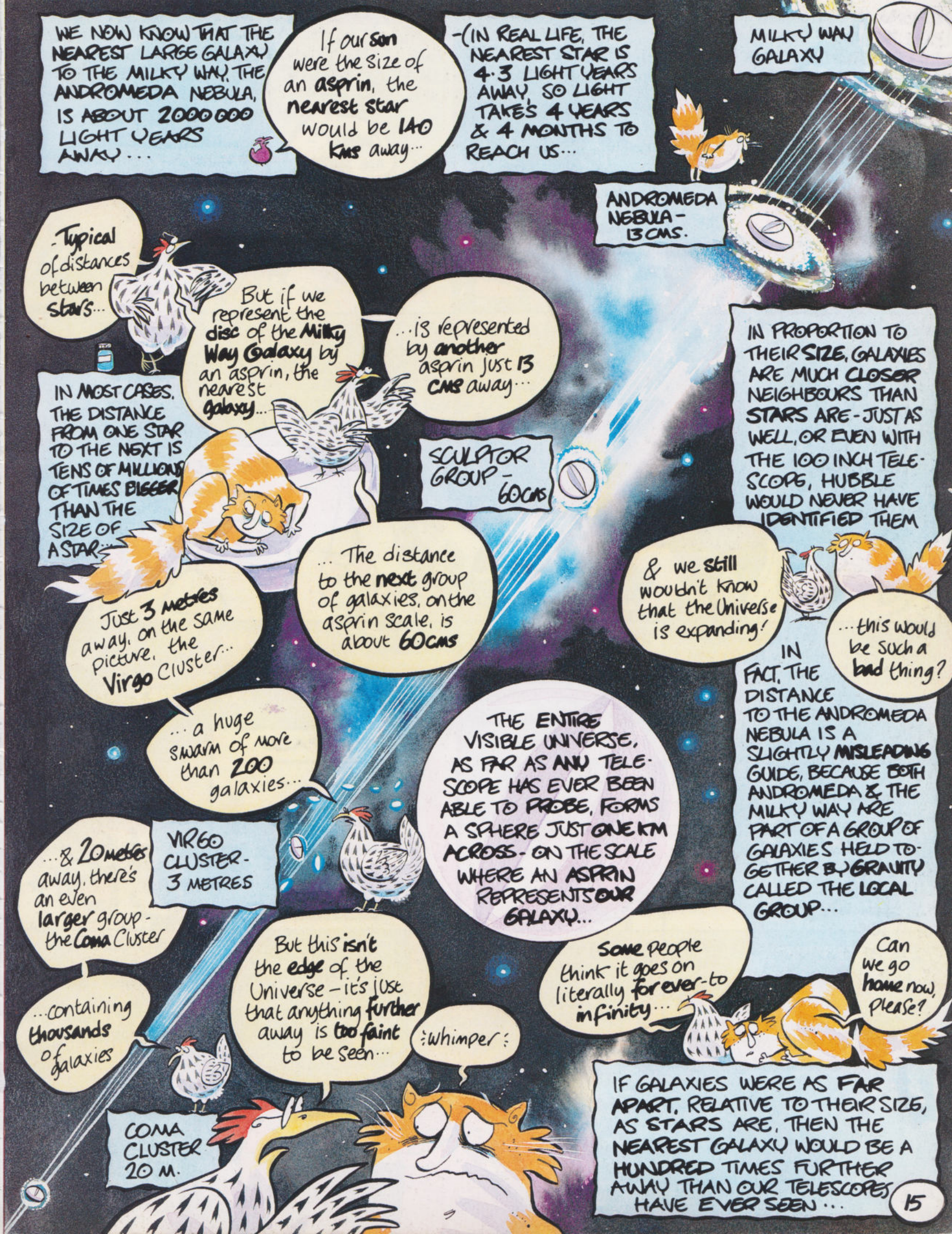
THE SUN ORBITS IN THE PLANE OF THIS DISC, ABOUT **30000** LIGHT YEARS OUT FROM THE CENTRE. (3/5 OF THE WAY TO THE EDGE. THE WHOLE KIT & CABOODLE IS HELD TOGETHER BY **GRAVITY**

IT WAS ONLY IN THE 1920s THAT AMERICAN ASTRONOMER EDWIN **HUBBLE**, USING THE NEW 100-INCH TELESCOPE AT **MOUNT WILSON** IN CALIFORNIA

(THE BIGGEST TELESCOPE IN THE WORLD UNTIL AFTER WORLD WAR II) FIRST PROVED THAT FAINT PATCHES OF **LIGHT** SEEN ON THE SKY ARE REALLY **OTHER** **GALAXIES**...

- IN MANY CASES, EVERY BIT AS **BIG** AS OUR OWN MILKY WAY - & THEN DISCOVERED THE **REDSHIFT** **EFFECT**...

THAT PUT GENERAL RELATIVITY ON A SECURE FOOTING AS THE **BEST** MATHEMATICAL DESCRIPTION OF THE EXPANDING UNIVERSE, **GOT RID** OF EINSTEIN'S **FIDDLE** **FACTOR**, & LAID THE FOUNDATIONS FOR **MODERN** **COSMOLOGY**...


WE NOW KNOW THAT THE NEAREST LARGE GALAXY TO THE MILKY WAY, THE ANDROMEDA NEBULA, IS ABOUT 2000000 LIGHT YEARS AWAY...
If our son were the size of an asprin, the nearest star would be 140 kms away...
-(IN REAL LIFE, THE NEAREST STAR IS 4·3 LIGHT YEARS AWAY, SO LIGHT TAKES 4 YEARS & 4 MONTHS TO REACH US...
MILKY WAY GALAXY
ANDROMEDA NEBULA - 13 CMS.
-Typical of distances between stars...
But if we represent the disc of the Milky Way Galaxy by an asprin, the nearest galaxy...
...is represented by another asprin just 13 cms away...
IN MOST CASES, THE DISTANCE FROM ONE STAR TO THE NEXT IS TENS OF MILLIONS OF TIMES BIGGER THAN THE SIZE OF A STAR...
SCULPTOR GROUP - 60CMS
IN PROPORTION TO THEIR SIZE, GALAXIES ARE MUCH CLOSER NEIGHBOURS THAN STARS ARE - JUST AS WELL, OR EVEN WITH THE 100 INCH TELESCOPE, HUBBLE WOULD NEVER HAVE IDENTIFIED THEM
... The distance to the next group of galaxies, on the asprin scale, is about 60cms
& we still wouldn't know that the Universe is expanding!
...this would be such a bad thing?
Just 3 metres away, on the same picture, the Virgo Cluster...
IN FACT, THE DISTANCE TO THE ANDROMEDA NEBULA IS A SLIGHTLY MISLEADING GUIDE, BECAUSE BOTH ANDROMEDA & THE MILKY WAY ARE PART OF A GROUP OF GALAXIES HELD TOGETHER BY GRAVITY CALLED THE LOCAL GROUP...
...a huge swarm of more than 200 galaxies...
THE ENTIRE VISIBLE UNIVERSE, AS FAR AS ANY TELESCOPE HAS EVER BEEN ABLE TO PROBE, FORMS A SPHERE JUST ONE KM ACROSS - ON THE SCALE WHERE AN ASPRIN REPRESENTS OUR GALAXY...
VIRGO CLUSTER - 3 METRES
...& 20 metres away, there's an even larger group - the Coma Cluster
...containing thousands of galaxies
But this isn't the edge of the Universe - it's just that anything further away is too faint to be seen...
:whimper:
Some people think it goes on literally for ever - to infinity...
Can we go home now, please?
COMA CLUSTER 20 M.
IF GALAXIES WERE AS FAR APART, RELATIVE TO THEIR SIZE, AS STARS ARE, THEN THE NEAREST GALAXY WOULD BE A HUNDRED TIMES FURTHER AWAY THAN OUR TELESCOPES HAVE EVER SEEN...
15

MODERN COSMOLOGY BEGAN WITH GENERAL RELATIVITY ALONG WITH THE PREDICTION THAT THE UNIVERSE IS EXPANDING. THE KEY INSIGHT FROM EINSTEIN'S WORK IS THAT SPACE ITSELF - (OR SPACETIME) IS BENT...

THIS MEANS THAT THE GEOMETRY OF SPACETIME IS NOT THE SAME AS THE EUCLIDEAN GEOMETRY WE LEARNED AT SCHOOL -

We did?

- WHICH ONLY APPLIES ACCURATELY TO FLAT SURFACES

CRASH!

S'true!

AS WELL AS THE DISTORTIONS IN SPACETIME PRODUCED BY LUMPS OF MATTER LIKE THE SUN...

'matter' - not 'batter'

ALEXIS THE DIARIES

THE OVERALL BACKGROUND SPACE OF THE UNIVERSE IS NOT ONLY EXPANDING, BUT CURVED...

SINCE SPACE OCCUPIES 3 DIMENSIONS, THE BENDING MUST INVOLVE A 4TH DIMENSION - OR A 5TH IF YOU RECKON TIME IS THE 4TH...

MOST PEOPLE HAVE TROUBLE PICTURING 5 DIMENSIONS

BAM!

BUT YOU CAN GET A FEEL FOR WHAT'S GOING ON BY LOOKING AT WHAT HAPPENS TO GEOMETRY WHEN WE BEND A FLAT, 2-DIMENSIONAL SHEET OF PAPER..

THERE ARE 3 KINDS OF GEOMETRY THAT COULD APPLY TO SPACE. IF IT IS 'POSITIVELY CURVED' OR CLOSED LIKE THE SURFACE OF A SPHERE, THEN 'PARALLEL' LINES EVENTUALLY CROSS EACH OTHER - & THE ANGLES OF A TRIANGLE ADD UP TO MORE THAN 180°

CLOSED SPACE

IF IT IS 'NEGATIVELY CURVED' OR OPEN LIKE A MOUNTAIN PASS OR A SADDLE SURFACE, THEN PARALLEL LINES DIVERGE FROM ONE ANOTHER & THE ANGLES ADD UP TO LESS THAN 180°

OPEN SPACE

THE 3RD POSSIBILITY, FLAT SPACE, IS A SPECIAL CASE DIVIDING THE OTHER TWO POSSIBILITIES.

IN FLAT SPACE, & ONLY IN FLAT SPACE, PARALLEL LINES ALWAYS STAY THE SAME DISTANCE APART, & THE ANGLES OF A TRIANGLE ADD UP TO 180°, AS EUCLID EXPLAINED

FLAT SPACE

Tell that to Euclid...

IN PRINCIPLE, YOU COULD FIND OUT THAT THE EARTH IS SPHERICAL, & WORK OUT ITS SIZE BY DRAWING HUGE TRIANGLES ON THE SURFACE OF THE SAHARA DESERT & MEASURING THEIR ANGLES EXTREMELY ACCURATELY.

IN 3-DIMENSIONAL SPACE, THE EQUIVALENT MEASUREMENTS INVOLVE COUNTING THE NUMBERS OF GALAXIES AT DIFFERENT DISTANCES FROM US...

...measuring how the volume of the Universe increases as we look further away...

FIRE

THESE MEASUREMENTS ARE VERY DIFFICULT, BUT THEY TELL US THAT OUR UNIVERSE IS NEARLY FLAT. IT MIGHT JUST BE OPEN - IT MIGHT JUST BE CLOSED

oh...

- & MIGHT BE A PROFOUND INSIGHT INTO HOW THE UNIVERSE CAME INTO BEING IN THE FIRST PLACE...

WE EXPLAIN WHY IN SECTION 5... ...pages 42/3

AS SOON AS NEWS OF GENERAL RELATIVITY ARRIVED, SOME CLEVER SODS SCIENTISTS USED IT TO PRODUCE THEIR OWN MATHEMATICAL DESCRIPTIONS OF THE UNIVERSE - OR RATHER, THE UNIVERSES...

- IT TURNED OUT THAT EINSTEIN'S EQUATIONS PROVIDE A DESCRIPTION OF ALL KINDS OF POSSIBLE UNIVERSES, SOME OPEN SOME CLOSED, SOME FLAT...

Some as bent as £2 notes! Get yer lovely Universes!

HONEST BOFFIN

THERE IS JUST ONE BASIC SET OF EQUATIONS - BUT WHEN YOU'VE SOLVED THEM, YOU CAN GET LOTS OF DIFFERENT ANSWERS

Nice, eh?

- all quality stuff...

ONE SET OF SOLUTIONS PROBABLY DESCRIBES OUR UNIVERSE - BUT WE DON'T KNOW EXACTLY WHICH ONE...

C'mon - you might pick the lucky one!

...& all of 'em right!

- Make your reputation in theoretical physics!

I thought they were supposed to know...

Don't worry - they know enough to make it all worthwhile

A DUTCHMAN, WILLEM DE SITTER SOON FOUND, LIKE EINSTEIN, THAT EVEN WHEN YOU TRIED TO FIND SOLUTIONS THAT DESCRIBE A STATIC UNIVERSE, THEY COME WITH BUILT-IN EXPANSION...

Lovely, ain't they? - Take a set home for the wife...

THE FIRST PERSON TO APPRECIATE THAT THE EXPANSION IS AN INTEGRAL PART OF THE EQUATIONS, & BELONGS IN COSMOLOGY FROM THE WORD GO - WAS A RUSSIAN, ALEXANDER FRIEDMAN...

H'mm...

- That's 'GO' spelt 'B-A-N-G'!

WHO WAS ALSO THE FIRST MATHEMATICIAN TO REALISE THAT HE WAS DEALING WITH A FAMILY OF SOLUTIONS TO EINSTEIN'S EQUATIONS...

FRIEDMAN SHOWED THAT IN SOME CASES, THE UNIVERSE EXPANDS - FOREVER...

BRAVO!

BUT IN OTHER CASES IT EXPANDS OUT TO A CERTAIN SIZE - THEN COLLAPSES BACK UPON ITSELF. (THE FIRST IS OPEN, THE SECOND CLOSED)

OR

BUT THE PERSON (OR PARSON) WHO DID MOST AT THE END OF THE 1920s TO PUBLICISE THE IDEA THAT THE UNIVERSE HAD STARTED OUT IN A SUPER-DENSE STATE & HAS BEEN EXPANDING EVER SINCE (EVEN IF IT MIGHT ONE DAY RECOLLAPSE) -

- WAS A BELGIAN PRIEST GEORGE LEMAÎTRE

That's a very old joke...

THE 'FATHER OF COSMOLOGY'

HE PUT THE MATHEMATICS OF EXPANDING SPACE & THE OBSERVATIONS OF RECEDING GALAXIES TOGETHER, & CONCLUDED THAT LONG AGO, EVERYTHING IN THE UNIVERSE HAD BEEN PILED UP IN WHAT HE CALLED THE PRIMEVAL ATOM.

The Father of Cosmology, I presume?

HIS IMAGINATION FAILED HIM BEFORE HE GOT BACK TO THE SINGULARITY AT THE MOMENT OF CREATION

JEHOVAH'S NURSERIES
F1 HYBRIDS
CONTS: 1 JUMBO UNIVERSAL COSMIC SEED
YOU WILL GET

- & HE ENVISAGED A TIME WHEN THE ENTIRE CONTENT OF THE UNIVERSE WAS PACKED INTO A SPHERE ABOUT 50 TIMES BIGGER THAN OUR SUN...

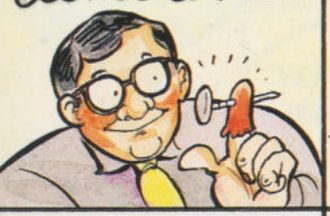
needs no compost!

...WHICH THEN EXPLODED OUTWARDS, BREAKING UP INTO FRAGMENTS THAT BECAME THE ATOMS, STARS & GALAXIES WE KNOW...

MODERN COSMOLOGY STILL HAS THIS PICTURE AT IT'S HEART - THOUGH NOW COSMOLOGISTS CAN IMAGINE BACK TO A TIME WHEN THE UNIVERSE WAS EVEN MORE COMPACT & DENSE...

THE STORY of A SCIENTIFIC JOKE

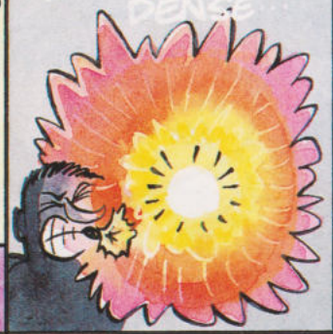
THE NEXT LEAP OF IMAGINATION CAME IN THE 1940s FROM A RUSSIAN PRACTICAL JOKER, GEORGE GAMOW



HE WAS ALSO A PHYSICIST, THEN LIVING IN THE USA - HAVING FOUND THAT STALIN'S REGIME DIDN'T SUIT HIS PERSONALITY...

BEFORE HE LEFT RUSSIA, GAMOW HAD BEEN ONE OF FRIEDMAN'S STUDENTS - LEARNING ABOUT COSMOLOGY FROM THE MASTER HIMSELF...

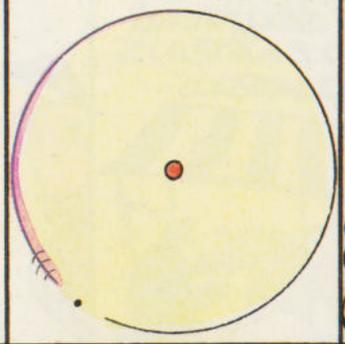
GAMOW CAME UP WITH THE IDEA THAT THE BIG BANG MUST HAVE BEEN VERY HOT AS WELL AS BEING VERY DENSE



-& WAS THE FIRST PERSON TO TRY TO EXPLAIN SCIENTIFICALLY WHERE ALL THE VARIETY OF ELEMENTS IN THE UNIVERSE HAD COME FROM...

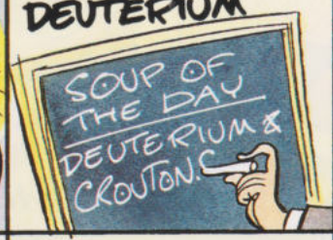
HE KNEW THAT IF A NEUTRON (A FUNDAMENTAL PARTICLE, SMALLER THAN AN ATOM) IS LEFT TO IT'S OWN DEVICES IT WILL DECAY, SPITTING OUT AN ELECTRON, & TURNING IT INTO A PROTON

A HYDROGEN ATOM IS SIMPLY A PROTON WITH AN ELECTRON ORBITING OUTSIDE IT...



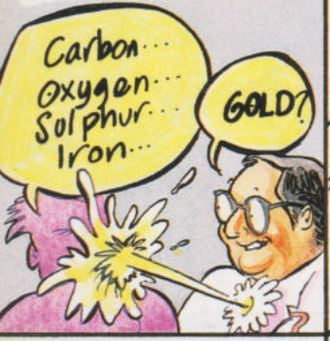
SO A COSMIC ATOM THAT WAS MADE OF NEUTRONS WOULD AUTOMATICALLY PRODUCE HYDROGEN OUT OF THE BIG BANG (GAMOW PREFERRED THE TERM COSMIC EGG)

BUT IF A PROTON & A NEUTRON COLLIDE WITH ONE ANOTHER IN A BREW AS HOT & DENSE AS THE BIG BANG WAS, THEY STICK TOGETHER TO FORM 'HEAVY HYDROGEN' - OR DEUTERIUM

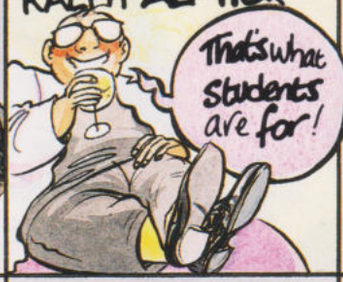


FURTHER COLLISIONS EASILY BUILD UP ATOMIC NUCLEI OF THE NEXT LIGHTEST ELEMENT - HELIUM - PROVIDED CONDITIONS ARE STILL HOT & DENSE...

GAMOW HOPED THAT COLLISIONS INVOLVING HELIUM NUCLEI WOULD BUILD UP MORE & MORE COMPLEX ELEMENTS

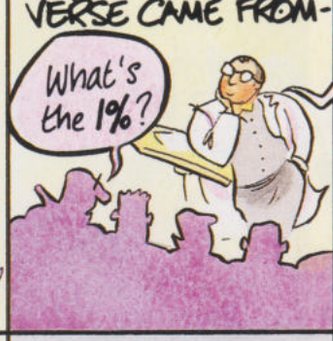


WHEN HE TRIED TO WORK THIS OUT IN THE BIG BANG, HE WAS PARTLY DISAPPOINTED. THE CALCULATIONS WERE CARRIED OUT BY HIS STUDENT, RALPH ALPHER -



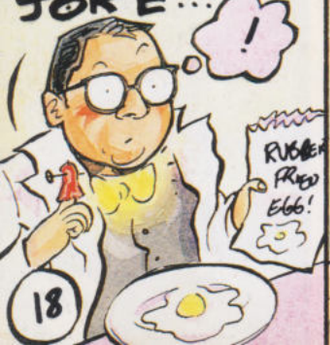
SHOWING THAT IN THE HOT BIG BANG IT WAS EASY TO MAKE HYDROGEN & HELIUM - BUT ANYTHING ELSE WAS VIRTUALLY IMPOSSIBLE.

UNDAUNTED, GAMOW TOLD EVERYONE WHO'D LISTEN THAT AS HIS THEORY EXPLAINED WHERE 99% OF THE UNIVERSE CAME FROM -



- HE'D LET SOMEONE ELSE WORK OUT WHERE THE EXTRA 1% OF ELEMENTS CAME FROM...

WHEN GAMOW & ALPHER WERE READY TO PUBLISH THEIR RESULTS, GAMOW THOUGHT OF THE JOKE...

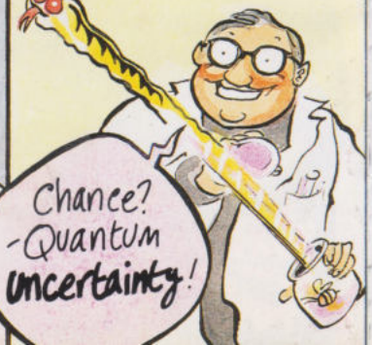


BEFORE SENDING THE PAPER OFF TO THE STAID JOURNAL, THE PHYSICAL REVIEW, HE ADDED THE NAME OF PHYSICIST HANS BETHE TO THE LIST OF AUTHORS

EVEN THOUGH BETHE WORKED IN A DIFFERENT CITY, & HADN'T ANYTHING TO DO WITH IT, ANYWAY...

THE PAPER WAS PUBLISHED WITH ALL 3 NAMES ON IT. NO ASTRONOMER EVER REFERS TO IT AS ANYTHING EXCEPT THE 'ALPHA BETA GAMMA' PAPER...

BY CHANCE, IT WAS PUBLISHED ON APRIL 1ST, 1948 -



THE BIG BANG CALCULATIONS GAVE GAMOW, ALPHER & ANOTHER STUDENT, ROBERT HERMAN

Pity he wasn't called Delter...

- A WAY TO TAKE THE TEMPERATURE OF THE UNIVERSE AT THE TIME THE NUCLEAR REACTIONS THAT MADE HELIUM WERE GOING ON.

Not that way...

THEY REALISED THAT THE FIREBALL OF RADIATION FROM THE BIG BANG WOULD STILL FILL THE UNIVERSE TODAY...

...not that sort of radiation

EVEN THOUGH IT'S BEEN EXPANDING & COOLING FOR BILLIONS OF YEARS, THEY CALCULATED THAT IT WOULD NOW HAVE A TEMPERATURE OF ABOUT 5K —

...MINUS DEGREES...

BUT THEY NEVER IMAGINED THAT RADIO ASTRONOMY TECHNIQUES WOULD SOON BE SENSITIVE ENOUGH TO MEASURE THE WEAK BACKGROUND HISS OF RADIATION...

I thought that was just background noise on the Archers...

That too...

THE MEASUREMENTS WERE ACTUALLY MADE IN THE 1960s, GIVING THE TEMPERATURE OF THE RADIATION AS JUST UNDER 3K -

...MINUS DEGREES...

- PROVIDING THE CLINCHING EVIDENCE THAT PERSUADED MOST ASTRONOMERS THAT THE BIG BANG REALLY DID HAPPEN...

Whimper...

- THAT THE UNIVERSE WAS INDEED BORN IN A SUPERDENSE FIREBALL ABOUT 15 BILLION YEARS AGO...

THE RESULT WAS AN EXPLOSION OF INTEREST IN THE BIG BANG IDEA, LEADING TO NEW THEORIES ABOUT THE BIRTH & DEATH OF THE UNIVERSE...

What?

Rubbish!

BUT WHEREAS THE 'OLD' BIG BANG THEORY WAS BASED PURELY ON GENERAL RELATIVITY —

Is that copyright?

I need to see my agent...

- THE NEW IDEAS TAKE ON BOARD ANOTHER GREAT DEVELOPMENT IN 20TH CENTURY SCIENCE - QUANTUM THEORY!

SCREAM!

What about the other 1% of elements, then?

- you, me, bats, newts, Blackpool Tower?

In fact, Fred Hoyle in the 1950s showed how all the other elements are actually made in the stars...

INSIDE A STAR MIGHT NOT BE AS HOT AS THE BIG BANG ITSELF WAS - BUT STARS ARE AROUND FOR BILLIONS OF YEARS...

Oh, it's hot all right...

- So there's plenty of time for atomic nuclei to bash into one another & stick together...

THE HEAVY ELEMENTS THEN GET SPREAD OUT THROUGH SPACE WHEN SOME STARS EXPLODE AS SUPERNOVAS...

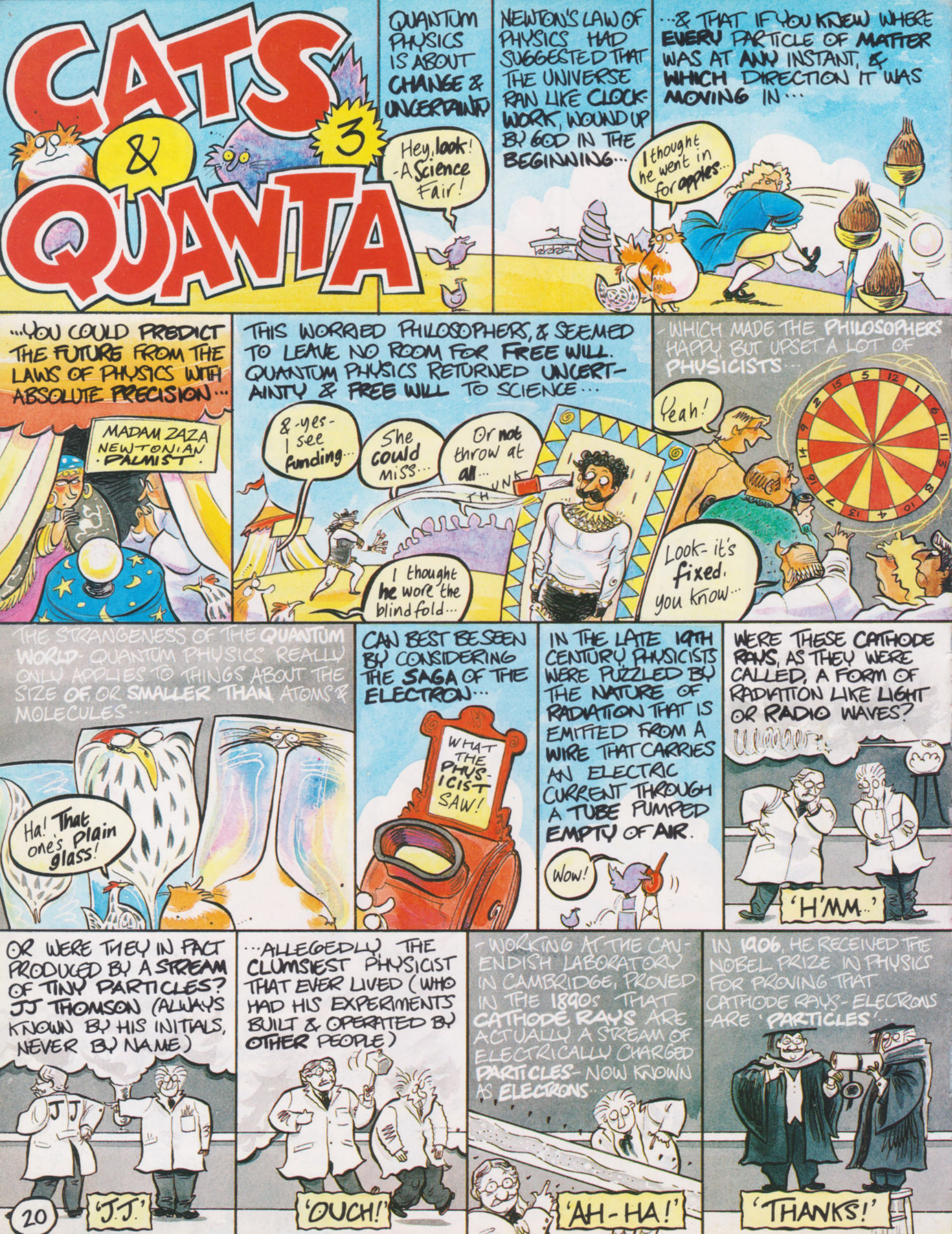
Actually, one of his colleagues, Willy Fowler, got it...

Like most of the scientific establishment, the Nobel Prize committee had been annoyed by some of Hoyle's later & more cranky ideas...

- like Archeopteryx being a fake...

H'm, he wouldn't hold with talking chickens, then...

Wow! I'll bet he got the Nobel Prize for that!


CATS & QUANTA 3
QUANTUM PHYSICS IS ABOUT CHANGE & UNCERTAINTY
Hey, look! - A Science Fair!
NEWTON'S LAW OF PHYSICS HAD SUGGESTED THAT THE UNIVERSE RAN LIKE CLOCK-WORK, WOUND UP BY GOD IN THE BEGINNING...
...& THAT IF YOU KNEW WHERE EVERY PARTICLE OF MATTER WAS AT ANY INSTANT, & WHICH DIRECTION IT WAS MOVING IN...
I thought he went in for apples...
...YOU COULD PREDICT THE FUTURE FROM THE LAWS OF PHYSICS WITH ABSOLUTE PRECISION...
MADAM ZAZA NEWTONIAN PALMIST
THIS WORRIED PHILOSOPHERS, & SEEMED TO LEAVE NO ROOM FOR FREE WILL. QUANTUM PHYSICS RETURNED UNCERTAINTY & FREE WILL TO SCIENCE...
& yes - I see funding...
She could miss...
Or not throw at all...
I thought he wore the blindfold...
- WHICH MADE THE PHILOSOPHERS HAPPY, BUT UPSET A LOT OF PHYSICISTS...
Yeah!
Look - it's fixed, you know...
THE STRANGENESS OF THE QUANTUM WORLD - QUANTUM PHYSICS REALLY ONLY APPLIES TO THINGS ABOUT THE SIZE OF, OR SMALLER THAN, ATOMS & MOLECULES...
Ha! That one's plain glass!
CAN BEST BE SEEN BY CONSIDERING THE SAGA OF THE ELECTRON...
WHAT THE PHYSICIST SAW!
IN THE LATE 19TH CENTURY PHYSICISTS WERE PUZZLED BY THE NATURE OF RADIATION THAT IS EMITTED FROM A WIRE THAT CARRIES AN ELECTRIC CURRENT THROUGH A TUBE PUMPED EMPTY OF AIR.
Wow!
WERE THESE CATHODE RAYS, AS THEY WERE CALLED, A FORM OF RADIATION LIKE LIGHT OR RADIO WAVES?
'H'MM...'
OR WERE THEY IN FACT PRODUCED BY A STREAM OF TINY PARTICLES? JJ THOMSON (ALWAYS KNOWN BY HIS INITIALS, NEVER BY NAME)
JJ
'J.J.'
...ALLEGEDLY THE CLUMSIEST PHYSICIST THAT EVER LIVED (WHO HAD HIS EXPERIMENTS BUILT & OPERATED BY OTHER PEOPLE)
'OUCH!'
- WORKING AT THE CAVENDISH LABORATORY IN CAMBRIDGE, PROVED IN THE 1890s THAT CATHODE RAYS ARE ACTUALLY A STREAM OF ELECTRICALLY CHARGED PARTICLES - NOW KNOWN AS ELECTRONS...
'AH-HA!'
IN 1906, HE RECEIVED THE NOBEL PRIZE IN PHYSICS FOR PROVING THAT CATHODE RAYS - ELECTRONS - ARE 'PARTICLES'...
'THANKS!'
20

THIS WAS A **CRUCIAL** STEP IN SCIENCE BECAUSE IT PROVED THAT **ATOMS** ARE **NOT INDIVISIBLE** —

'THEY'RE **NOT**. THEY'RE **NOT**!'

NEGATIVELY CHARGED ELECTRONS CAN BE **KNOCKED OUT** OF THEM, LEAVING **POSITIVELY** CHARGED **IONS** BEHIND...

KLUNK

ALSO, THE CATHODE RAY TUBE LED DIRECTLY TO MODERN **TELEVISION** WHERE THE PICTURE IS '**PAINTED**' BY STREAMS OF ELECTRONS...

I wonder if we ever got to the **good** bit?

BUT ALL THIS WAS **BEFORE** QUANTUM PHYSICS **CHANGED** THE WAY PEOPLE LOOKED AT THE WORLD

THE BOSON

THE QUARK

IN THE **1920**s IT BECAME CLEAR THAT IF QUANTUM THEORY WERE **CORRECT** THEN ELECTRONS SHOULD **ALSO** BEHAVE AS **WAVES**...

IN **1927**, **GEORGE** THOMSON, **SON** OF J.J. WORKING AT THE UNIVERSITY OF ABERDEEN, CARRIED OUT EXPERIMENTS IN WHICH BEAMS OF **ELECTRONS** WERE BOUNCED OFF THE **ATOMS** IN A **CRYSTAL**...

Sort of scientific **glitter ball**...

THE **WAY** THE ELECTRON BEAMS WERE DEFLECTED (BY DIFFRACTION) SHOWED THAT THEY WERE BEHAVING LIKE **WAVES**, **NOT** A STREAM OF TINY **PARTICLES**...

GEORGE THOMSON HAD PROVED THAT **ELECTRONS** ARE **WAVES**, & HE RECIEVED THE NOBEL PRIZE FOR THIS DISCOVERY IN **1937**...

HIS **FATHER**, WHO GOT THE PRIZE **31** YEARS **EARLIER** (GEORGE WAS 14) FOR PROVING **ELECTRONS** ARE **PARTICLES**...

... LIVED TO SEE HIS **SON** GET IT FOR PROVING **ELECTRONS** ARE **WAVES**...

BOTH WERE **RIGHT**— ELECTRONS & OTHER SUBATOMIC PARTICLES ARE BOTH WAVES & PARTICLES— THE NOBEL COMMITTEE **HADN'T** GOT IT WRONG.

WHEN YOU CARRY OUT A **TEST** DESIGNED TO **LOOK** FOR PARTICLES, THEY **RESPOND** LIKE PARTICLES...

WHEN YOU CARRY OUT A TEST DESIGNED TO LOOK FOR **WAVES** THEY **ACT** LIKE WAVES...

BUT WHEN NOBODY'S **LOOKING**, IT'S IMPOSSIBLE TO **SAY** WHAT THE ELECTRONS ARE **DOING**

MADAM ALEXIS **QUANTUM** PALMIST

THIS **MYSTERY** LIES AT THE **HEART** OF QUANTUM PHYSICS...

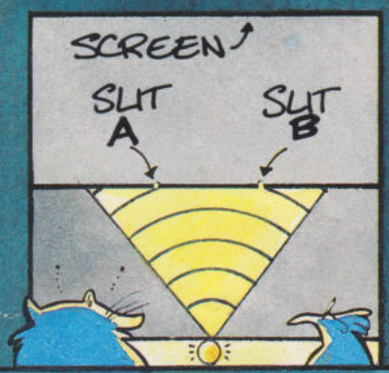
THE BOFFIN CHICKEN WILL **PROBABLY** ANSWER YOUR QUESTIONS

RICHARD FEYNMAN ONCE SAID THAT THE CENTRAL MYSTERY OF QUANTUM PHYSICS IS CONTAINED IN THE 'EXPERIMENT WITH TWO HOLES'. THE CLEAREST PRACTICAL DEMONSTRATION OF WHAT HE MEANT CAME IN 1989, WHEN JAPANESE RESEARCHERS SUCCEEDED IN BUILDING AN EXPERIMENT SO SUBTLE...

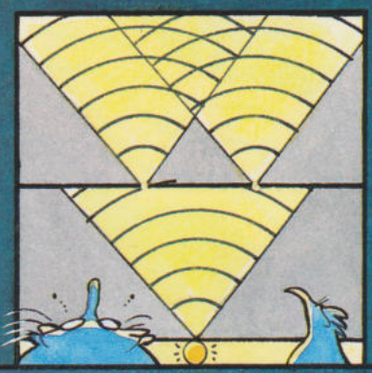
...IT COULD SHOOT INDIVIDUAL ELECTRONS THROUGH A SCREEN WITH 2 HOLES IN & DETECT THEIR ARRIVAL ON THE OTHER SIDE ON A TV SCREEN...

H'm

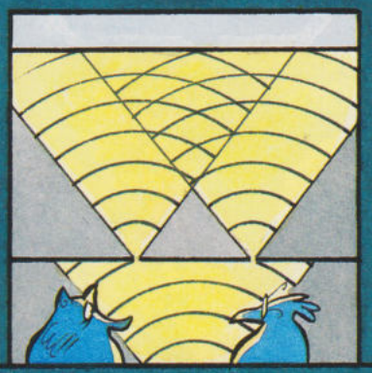
IF WAVES PASS THROUGH TWO HOLES IN THIS WAY,



THE WAVE PATTERN FROM ONE HOLE INTERFERES WITH THE WAVE PATTERN FROM THE OTHER HOLE-

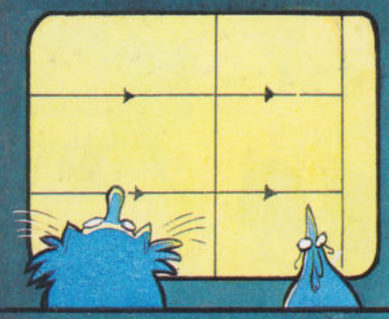


SO THAT ON THE OTHER SIDE OF THE HOLES THERE IS A SET OF INTERFERENCE FRINGES



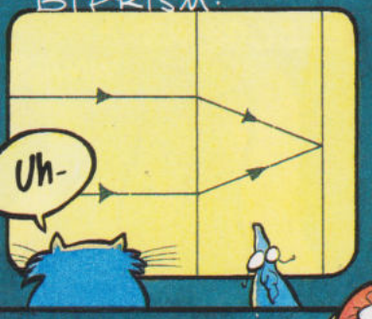
WITH THE WAVES ADDING TOGETHER IN SOME PLACES & CANCELLING EACH OTHER OUT IN BETWEEN.

IF A SERIES OF PARTICLES IS FIRED THROUGH 2 HOLES (FEYNMAN USED TO IMAGINE A MACHINE GUN BLASTING AWAY) -



THEN THERE SHOULD BE A LOT OF PARTICLES ARRIVING ON THE OTHER SIDE OF EACH HOLE- BUT NO INTERFERENCE...

THE JAPANESE FIRED ELECTRONS ONE AT A TIME FROM AN ELECTRON MICROSCOPE 'GUN' THROUGH A 'DOUBLE SLIT' -CALLED AN ELECTRON BIPRISM.

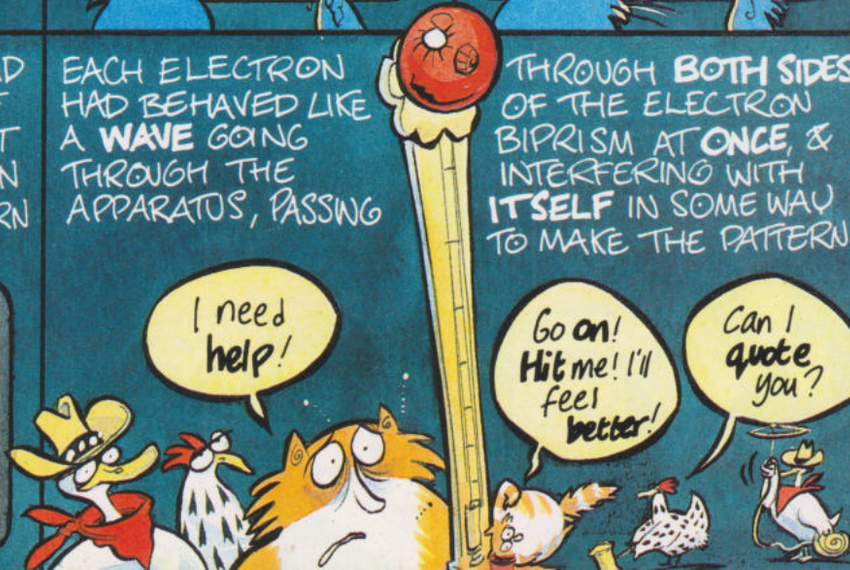


WHEN EACH ELECTRON ARRIVED AT THE TV SCREEN, IT MADE A TINY SPOT OF LIGHT, DEMONSTRATING THAT IT WAS A SINGLE PARTICLE.

BUT AFTER THOUSANDS OF ELECTRONS HAD BEEN FIRED AT THE SCREEN ONE AT A TIME...

THE PICTURE THAT HAD BUILT UP WAS ONE OF ALTERNATING BRIGHT & DARK STRIPES - AN INTERFERENCE PATTERN

EACH ELECTRON HAD BEHAVED LIKE A WAVE GOING THROUGH THE APPARATUS, PASSING THROUGH BOTH SIDES OF THE ELECTRON BIPRISM AT ONCE, & INTERFERING WITH ITSELF IN SOME WAY TO MAKE THE PATTERN.



BUT WHEN THE WAVE ARRIVED AT THE SCREEN, IN EACH CASE IT 'COLLAPSED' TO MARK THE ARRIVAL OF A SINGLE PARTICLE AT A **UNIQUE POINT**.

OKAY— I'll **watch**...

THIS, SAID FEYNMAN, IS 'ABSOLUTELY **IMPOSSIBLE** TO EXPLAIN IN ANY **CLASSICAL** WAY'.

How about **Cubist**? Post-**Modern**? **Gothic Revival**?!

THE WAY IT IS EXPLAINED IN QUANTUM PHYSICS IS IN TERMS OF **PROBABILITY** & **STATISTICS**...

Yes... you might **possibly** hit the target, but **probably**...

NOBODY CAN SAY IN **ADVANCE** WHERE IN THE SCREEN ANY PARTICULAR ELECTRON FIRED FROM THE OTHER SIDE OF THE 2 HOLES WILL **ARRIVE**-

Ahem!

-THOUGH WE **CAN** SAY THAT OUT OF EACH 1000 ELECTRONS A CERTAIN PRECISE FRACTION WILL ARRIVE **HERE**, & A CERTAIN FRACTION **THERE**.

BUT CALCULATIONS MADE ON THE BASIS OF **WAVE** BEHAVIOUR SHOW THAT THE ELECTRON IS MORE LIKELY TO ARRIVE IN **SOME** PLACES...

All you **need** to make a **TV** work...

...THE **BRIGHT** STRIPES... THAN IN **OTHERS** — THE **DARK** STRIPES.

Extraordinary, **isn't** it?

IT'S AS IF A **WAVE** OF **PROBABILITY** PASSES THROUGH THE APPARATUS-

Yeah...

It's just **SKIN**...

& EACH ELECTRON IS ASSIGNED ITS PLACE BY **CHANCE** IN LINE WITH THE RULE OF **PROBABILITY**-

- THE **SAME** RULES THAT **CASINO** OPERATORS USE TO THEIR ADVANTAGE.

Pssst!

THE ELECTRON MIGHT BE **ANYWHERE**, UNTIL ITS POSITION IS MEASURED OR IT RUNS INTO A SCREEN...

Rien ne va plus...

THEN, IT HAS TO BE SOMEWHERE, & THE UNCERTAINTY **DISAPPEARS** AS THE WAVEFUNCTION **COLLAPSES**.

No! - Not **Hilda**!

Wavefunction collapse! **Red** wins!

THIS INTERPRETATION OF QUANTUM PHYSICS IS WHAT LED **EINSTEIN** TO MAKE HIS FAMOUS REMARK THAT HE DIDN'T BELIVE '**GOD PLAYS DICE**'.

A-**ha**!

Eject!

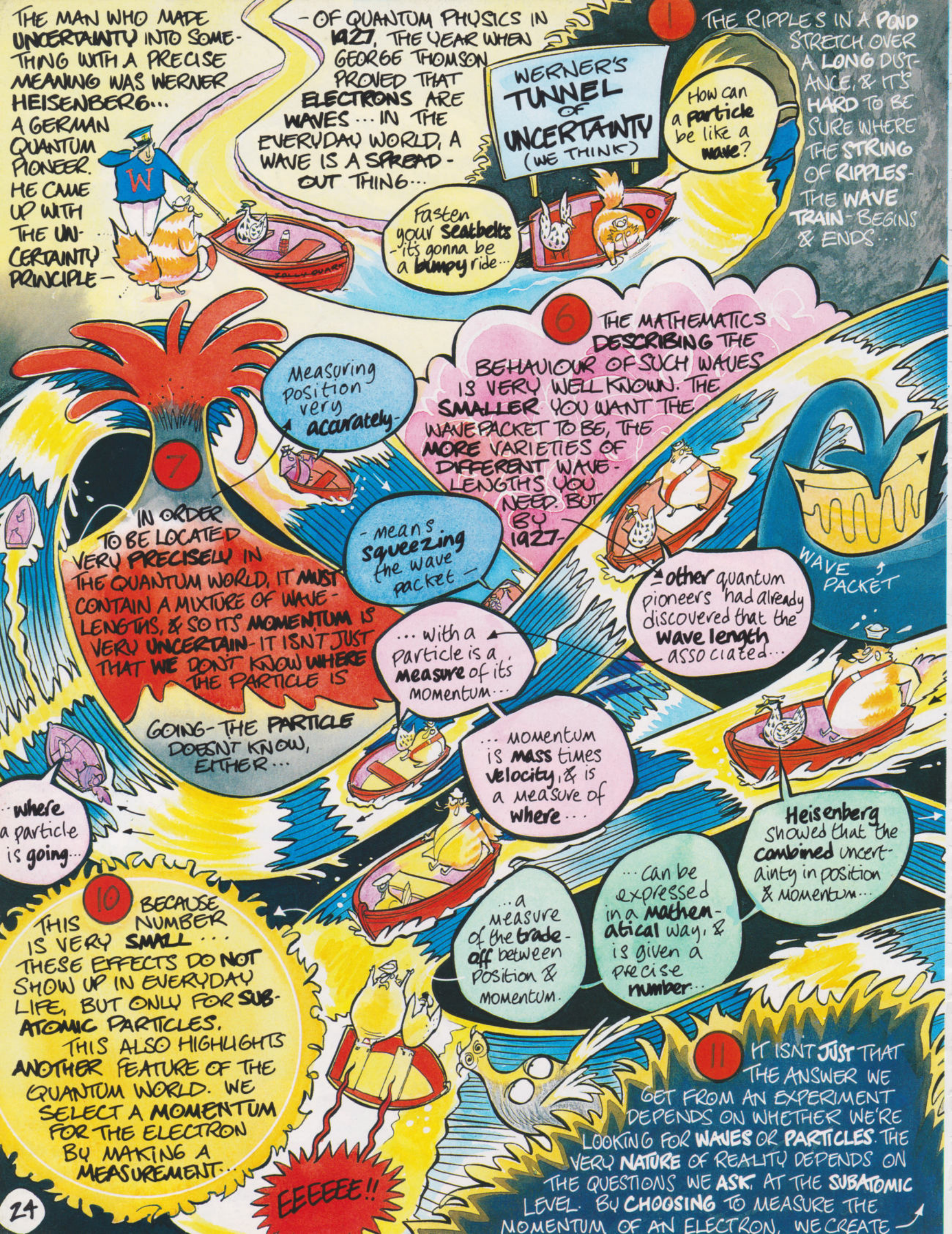
TO THE **END** OF HIS **LIFE**, EINSTEIN BELIVED THAT THERE MUST BE SOME UNDERLYING **CLOCKWORK** AT WORK: GUIDING EACH ELECTRON ALONG A PERFECTLY DEFINED **PATH**...

WE HAVE **NO** IDEA WHAT AN ELECTRON, OR OTHER PARTICLE IS DOING -

-it's got to be **here**!

-UNLESS WE **MEASURE** IT; & EVEN WHEN WE MEASURE IT, WE CAN'T BE CERTAIN WHERE IT **IS**, & WHERE IT'S **GOING** — AT THE **SAME TIME**...

I don't know **either** way...


THE MAN WHO MADE UNCERTAINTY INTO SOMETHING WITH A PRECISE MEANING WAS WERNER HEISENBERG... A GERMAN QUANTUM PIONEER. HE CAME UP WITH THE UNCERTAINTY PRINCIPLE—
—OF QUANTUM PHYSICS IN 1927, THE YEAR WHEN GEORGE THOMSON PROVED THAT ELECTRONS ARE WAVES... IN THE EVERYDAY WORLD, A WAVE IS A SPREAD-OUT THING...
WERNER'S TUNNEL OF UNCERTAINTY (WE THINK)
1
THE RIPPLES IN A POND STRETCH OVER A LONG DISTANCE, & IT'S HARD TO BE SURE WHERE THE STRING OF RIPPLES - THE WAVE TRAIN - BEGINS & ENDS...
How can a particle be like a wave?
Fasten your seatbelts - it's gonna be a bumpy ride...
6
THE MATHEMATICS DESCRIBING THE BEHAVIOUR OF SUCH WAVES IS VERY WELL KNOWN. THE SMALLER YOU WANT THE WAVE PACKET TO BE, THE MORE VARIETIES OF DIFFERENT WAVE-LENGTHS YOU NEED. BUT BY 1927-
WAVE PACKET
Measuring position very accurately-
7
IN ORDER TO BE LOCATED VERY PRECISELY IN THE QUANTUM WORLD, IT MUST CONTAIN A MIXTURE OF WAVE-LENGTHS, & SO ITS MOMENTUM IS VERY UNCERTAIN - IT ISN'T JUST THAT WE DON'T KNOW WHERE THE PARTICLE IS GOING - THE PARTICLE DOESN'T KNOW, EITHER...
- means squeezing the wave packet -
- other quantum pioneers had already discovered that the wavelength associated...
... with a particle is a measure of its momentum...
... momentum is mass times velocity, & is a measure of where...
... where a particle is going...
Heisenberg showed that the combined uncertainty in position & momentum...
... can be expressed in a mathematical way, & is given a precise number...
... a measure of the trade-off between position & momentum.
10
BECAUSE THIS NUMBER IS VERY SMALL... THESE EFFECTS DO NOT SHOW UP IN EVERYDAY LIFE, BUT ONLY FOR SUBATOMIC PARTICLES. THIS ALSO HIGHLIGHTS ANOTHER FEATURE OF THE QUANTUM WORLD. WE SELECT A MOMENTUM FOR THE ELECTRON BY MAKING A MEASUREMENT...
EEEEEE!!
11
IT ISN'T JUST THAT THE ANSWER WE GET FROM AN EXPERIMENT DEPENDS ON WHETHER WE'RE LOOKING FOR WAVES OR PARTICLES. THE VERY NATURE OF REALITY DEPENDS ON THE QUESTIONS WE ASK. AT THE SUBATOMIC LEVEL. BY CHOOSING TO MEASURE THE MOMENTUM OF AN ELECTRON, WE CREATE →
24

2 BUT A PARTICLE IS A VERY WELL-DEFINED THING- WITH DEFINITE EDGES- WHICH OCCUPIES A DEFINITE PLACE AT A DEFINITE TIME. HOW CAN THESE TWO CONFLICTING IMAGES...
GULP..
3 ...BE RECONCILED. AS THEY MUST BE IF AN ELECTRON IS TO BE REGARDED AS BOTH WAVE & PARTICLE AT THE SAME TIME? - HEISENBERG REALISED THAT THE APPROPRIATE IMAGE IS OF...
4 ...LITTLE PACKETS OF WAVES - A SHORT WAVE TRAIN EXTENDING OVER A SMALL DISTANCE, ROUGHLY EQUIVALENT TO WHAT WE...
EEEEE!
5 ...TO WHAT WE THINK OF AS THE SIZE OF THE PARTICLE. SUCH A WAVE PACKET CAN BE PRODUCED WHEN SEVERAL (OR MANY) WAVES WITH DIFFERENT WAVELENGTHS INTERFERE WITH EACH OTHER - CANCELLING OUT EVERYWHERE EXCEPT IN THE REGION OF THE PACKET.
- 'What me'? 'What we' what?
Search me - I'm just an innocent bystander
It's confusing - All this...
Oh...
... practical uncertainty!
8 BUT MEASURING MOMENTUM (WHERE THE PARTICLE IS GOING) VERY ACCURATELY CORRESPONDS TO SELECTING OUT A PARTICULAR WAVE-
- producing a bigger spread in wavelength & more uncertainty in momentum.
9 -LENGTH FOR THE ELECTRON & THAT MEANS THE WAVE TRAIN STRETCHES OUT OVER A LONG DISTANCE, SO THE ELECTRON HAS A VERY ILL-DEFINED POSITION. IT ISN'T JUST THAT WE DON'T KNOW WHERE THE ELECTRON IS, NOW, THE ELECTRON ITSELF DOESN'T KNOW WHERE IT IS...
in a real sense, it's actually everywhere along the wave at once!
ern...
But it does know where it's going!
SCREAM!!
DUAL CHOICE EXIT. EXIT
12 - UNCERTAINTY ABOUT ITS POSITION; BY MEASURE ITS POSITION, WE CREATE UNCERTAINTY ABOUT WHERE ITS GOING. THIS WHOLE PACKAGE - UNCERTAINTY, WAVE/PARTICLE DUALITY & PROBABILITY, IS THE WAY REALITY DEPENDS ON WHAT...
- WE CHOOSE TO MEASURE - & CHOOSING TO FORMS THE STANDARD DESCRIPTION OF THE QUANTUM WORLD KNOWN AS -
- THE COPENHAGEN INTERPRETATION!

The COPENHAGEN INTERPRETATION

JUST ABOUT ANY TRIUMPH OF 20TH CENTURY SCIENCE HAS ITS ROOTS IN—

ONLY A FEW PHYSICISTS BOTHERED ABOUT THE WEIRDNESS OF IT ALL - LIKE EINSTEIN -

- & FEYNMAN - THE CLEVER ONES. THE AVERAGE QUANTUM MECHANIC DOESN'T KNOW, OR CARE

$$h = p\lambda$$

THEY GAVE LATER GENERATIONS A SET OF RECIPES FOR DEALING WITH THE QUANTUM WORLD - A QUANTUM COOKBOOK...

THE QUANTUM COOKS WHO FOLLOWED THEM DIDN'T WORRY WHAT THE RECIPES WERE ABOUT AS LONG AS THEY WORKED...

...WHERE THE RECIPES COME FROM. THE PIONEERS OF THE 1920s SET UP THE BASIC EQUATIONS, INCLUDING PROBABILITY & UNCERTAINTY FOR CALCULATING HOW EXPERIMENTS ARE LIKELY TO TURN OUT...

...QUANTUM PHYSICS IS THE BASIS OF OUR UNDERSTANDING OF ATOMS & NUCLEI. SO THE COOKBOOK IS ESSENTIAL FOR NUCLEAR PHYSICISTS WHO EITHER WORK WITH *FISSION OR WITH *NUCLEAR FUSION...

The craziest thing about it is — it works!

...& they worked a treat!

*Atomic bombs & all nuclear power stations to date...

*Hydrogen bombs & experimental attempts to make fusion reactors...

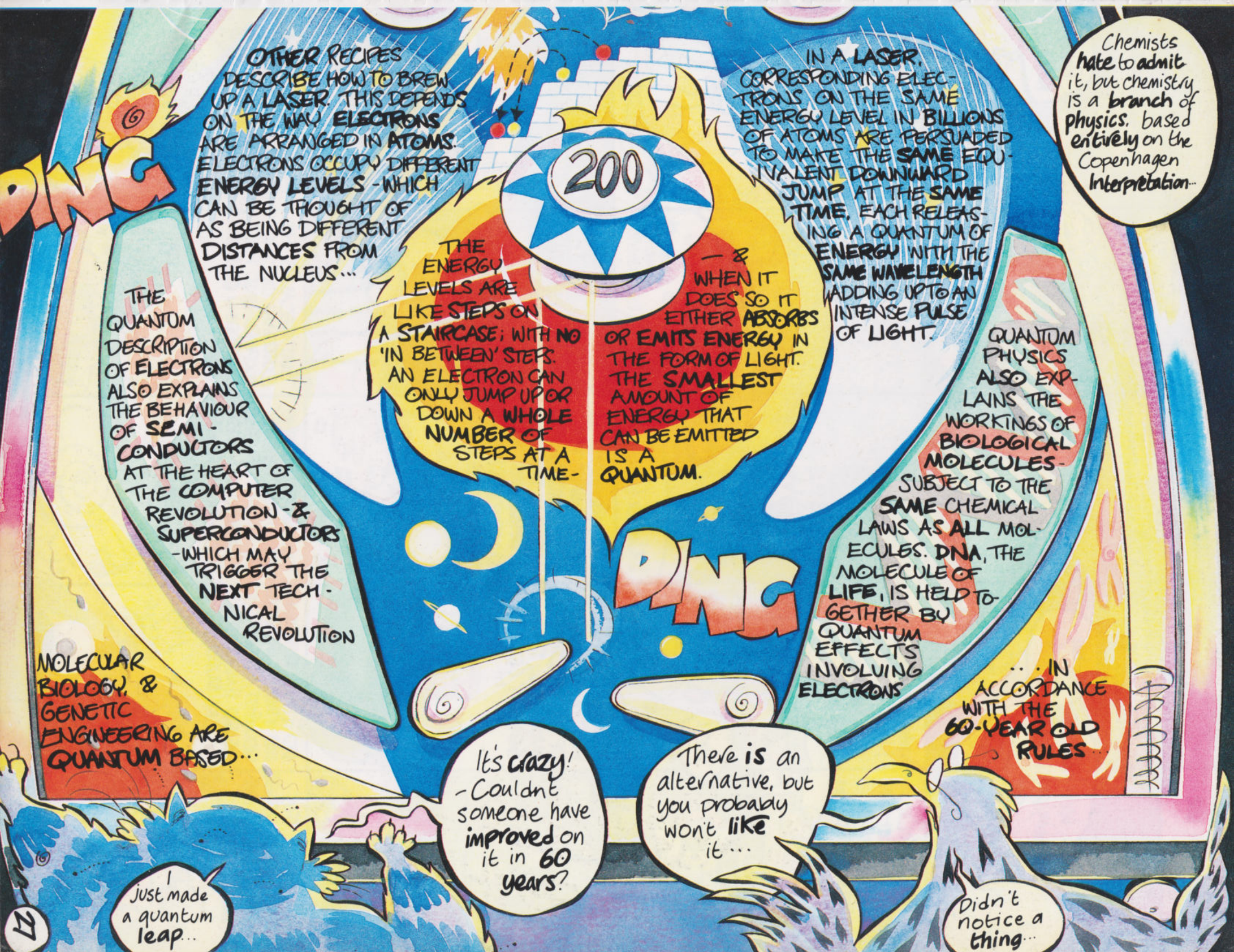
...on the behaviour of quantum particles!

This is more important than Einsteins $E=mc^2$, which tells you that energy might be produced from mass...

The Quantum Cookbook tells you how...

ELECTRONS ARE THE ARCHETYPAL QUANTUM PARTICLES, & EVERY ATOM CONSISTS OF A TINY CENTRAL NUCLEUS SURROUNDED BY A CLOUD OF ELECTRONS (BECAUSE OF ITS WAVE NATURE & UNCERTAINTY OF POSITION. EACH ELECTRON FORMS

...A CLOUD AROUND THE NUCLEUS - THE FACE AN ATOM SHOWS TO THE WORLD - TO OTHER ATOMS - IS THAT ELECTRON CLOUD. SO CHEMISTRY, WHICH IS ALL ABOUT THE WAY ATOMS INTERACT WITH EACH OTHER, DEPENDS ENTIRELY...


PING
OTHER RECIPES DESCRIBE HOW TO BREW UP A LASER. THIS DEPENDS ON THE WAY ELECTRONS ARE ARRANGED IN ATOMS. ELECTRONS OCCUPY DIFFERENT ENERGY LEVELS - WHICH CAN BE THOUGHT OF AS BEING DIFFERENT DISTANCES FROM THE NUCLEUS...
200
THE ENERGY LEVELS ARE LIKE STEPS ON A STAIRCASE; WITH NO 'IN BETWEEN' STEPS. AN ELECTRON CAN ONLY JUMP UP OR DOWN A WHOLE NUMBER OF STEPS AT A TIME-
— & WHEN IT DOES SO IT EITHER ABSORBS OR EMITS ENERGY IN THE FORM OF LIGHT. THE SMALLEST AMOUNT OF ENERGY THAT CAN BE EMITTED IS A QUANTUM.
IN A LASER, CORRESPONDING ELECTRONS ON THE SAME ENERGY LEVEL IN BILLIONS OF ATOMS ARE PERSUADED TO MAKE THE SAME EQUIVALENT DOWNWARD JUMP AT THE SAME TIME, EACH RELEASING A QUANTUM OF ENERGY WITH THE SAME WAVELENGTH ADDING UP TO AN INTENSE PULSE OF LIGHT.
Chemists hate to admit it, but chemistry is a branch of physics, based entirely on the Copenhagen interpretation...
THE QUANTUM DESCRIPTION OF ELECTRONS ALSO EXPLAINS THE BEHAVIOUR OF SEMI-CONDUCTORS AT THE HEART OF THE COMPUTER REVOLUTION - & SUPERCONDUCTORS - WHICH MAY TRIGGER THE NEXT TECHNICAL REVOLUTION
QUANTUM PHYSICS ALSO EXPLAINS THE WORKINGS OF BIOLOGICAL MOLECULES - SUBJECT TO THE SAME CHEMICAL LAWS AS ALL MOLECULES. DNA, THE MOLECULE OF LIFE, IS HELD TOGETHER BY QUANTUM EFFECTS INVOLVING ELECTRONS
MOLECULAR BIOLOGY, & GENETIC ENGINEERING ARE QUANTUM BASED...
... IN ACCORDANCE WITH THE 60-YEAR OLD RULES...
PING
I just made a quantum leap...
It's crazy! - Couldn't someone have improved on it in 60 years?
There is an alternative, but you probably won't like it...
Didn't notice a thing...
27

What d'you mean, 'you might not like it?'
Well- not many physicists do...
BUT SOME COSMOLOGISTS, LED BY STEPHEN HAWKING, THINK IT MAY BE THE BEST THING SINCE SLICED BREAD...
Yes, but I'm not...
THE ALTERNATIVE TO THE COPENHAGEN INTERPRETATION INVOLVES LOOKING IN A DIFFERENT WAY AT WHAT HAPPENS...
Hey...
...WHEN WE MEASURE A QUANTUM SYSTEM... DOES THE SPREAD OUT WAVE FUNCTION REALLY COLLAPSE?
...what's this?
You'll find out...
IF NOT, WHAT HAPPENS TO IT? THE POSSIBILITIES CAN BE PICTURED BY LOOKING AT THE FATE OF SCHRÖDINGER'S CAT...
Roll up, Roll up!!
Schrödinger's Cat, a mythical creature, was intensely disliked by Hawking
...who once said 'When I hear of Schrödinger's Cat, I reach for my gun...'
Well!
ERWIN SCHRÖDINGER A QUANTUM PIONEER WHO HATED THE IDEA THAT 'GOD PLAYS DICE' AS MUCH AS EINSTEIN DID-
Ladies & Gentlemen!
-INVENTED HIS FAMOUS CAT-IN-A-BOX PUZZLE TO SHOW HOW STUPID THE COPENHAGEN INTERPRETATION IS
KRACK!
I intend to attempt the experiment!
- For which I will need one volunteer!
eeeek!
SNATCH
HE ASKED: 'WHAT WOULD BE THE FATE OF A CAT LOCKED UP IN A BOX...
sob...
...WITH A PHIAL OF POISON, A SAMPLE OF RADIOACTIVE MATERIAL, & A GEIGER COUNTER?'
-ALL ARRANGED IN SUCH A WAY THAT IF THE RADIOACTIVE MATERIAL DECAYS, IT TRIGGERS THE COUNTER & SMASHES THE BOTTLE OF POISON...
PING
DING
PLINK
PLUNK
A
B
C
D
IN LINE WITH THE QUANTUM RULES, AFTER A CERTAIN TIME (PRECISELY KNOWN FROM THE COOKBOOK)
You knew about this!
THERE IS AN EXACT 50:50 CHANCE THAT THIS HAS HAPPENED...
Well, ain't that just great!
IF WE OPEN THE BOX, WE WILL EITHER SEE A LIVE CAT OR A DEAD CAT.
SSSSSSS
DO THE EXPERIMENT 100 TIMES & 50 TIMES YOU GET A DEAD CAT -& SO TIMES, THE CAT SURVIVES...
BOING
BOING
BUT WHAT IS IN THE BOX JUST BEFORE WE OPEN IT? THE COPENHAGEN INTERPRETATION SAYS-
THAT BECAUSE THE OUTCOME OF THE EXPERIMENT HAS NOT BEEN OBSERVED...
THE PROBABILITY WAVE FUNCTION HAS NOT COLLAPSED.
Damn right it hasn't!
28

– THE CAT IS SIMULTANEOUSLY BOTH DEAD AND ALIVE.

Hardly the cat…

ONLY WHEN WE LOOK DOES IT MAKE UP IT'S MIND WHICH IT SHOULD BE. THE WAVEFUNCTION COLLAPSES & THE UNIVERSE PROCEEDS ON ITS WAY…

…that's really why it's a 'thought' experiment!

FEW PEOPLE TOOK SCHRÖDINGER'S OBJECTION THAT THIS WAS NONSENSE SERIOUSLY UNTIL THE 1950s.

It's rubbish, I tell you!

THEN HUGH EVERETT, A GRADUATE STUDENT AT PRINCETON UNIVERSITY, SUGGESTED THAT THE WAVE FUNCTION DOESN'T HAVE TO COLLAPSE AT ALL…

What if…

WHAT THE QUANTUM EQUATIONS REALLY MEAN, HE SAID, IS THAT THERE ARE MANY WORLDS (IN THIS CASE, TWO)

? ?

–ONE CORRESPONDING TO EACH POSSIBLE WAVE FUNCTION, IN ONE UNIVERSE, WE OPEN THE BOX & FIND A DEAD CAT!

So good… So witty… So intelligent…

IN ANOTHER UNIVERSE (USUALLY CALLED A PARALLEL WORLD) – OUR COUNTERPARTS OPEN THE BOX & FIND A LIVE CAT…

–the other world, obviously–

BOTH ARE REAL, & NOTHING EVER COLLAPSES.

Right! I'm phoning the RSPCA now…

Can I listen?

EVERETT & A TINY MINORITY OF RESEARCHERS WHO TOOK UP THE IDEA SAID THAT THE–

There's this cat in a parallel world…

!

SAME THING HAPPENS AT THE QUANTUM LEVEL FOR EVERY CHOICE AN ELECTRON, OR OTHER QUANTUM PARTICLE, IS FACED WITH.

I'm cancelling my subscription!

THE UNIVERSE DIVIDES INTO AS MANY COPIES OF ITSELF–

AS IT TAKES FOR EVERY POSSIBLE OUTCOME OF EVERY POSSIBLE EXPERIMENT TO REALLY HAPPEN.

THE CATCH IS THAT WE CAN NEVER COMMUNICATE WITH THESE WORLDS

Too exhausting…

–THE GOOD THING ABOUT THE MANY WORLDS INTERPRETATION IS THAT IT GIVES THE SAME PICTURE –

AS THE COPENHAGEN INTERPRETATION FOR ANY PRACTICAL APPLICATION OF QUANTUM PHYSICS–

God as a sort of cosmic photocopier?

–LIKE DESIGNING A LASER, OR BUILDING A COMPUTER.

…how reassuring!

No, look–

THE RECIPE IS UNCHANGED. SCIENCE FICTION FANS LOVED IT.

Imagine – a world where Margaret Thatcher was a miner's wife…

BUT FEW PHYSICISTS GAVE IT MUCH TIME. UNTIL THEY BEGAN TO WONDER HOW TO DESCRIBE THE WHOLE UNIVERSE IN QUANTUM TERMS.

You get a Nobel prize…

DOES IT HAVE A WAVEFUNCTION, & IF SO, HOW DOES IT COLLAPSE?

Schrödinger uses a chicken in the experiment!

We do?

ahem! – Before we get into any of this, we want to tell you how quantum physics – either version–

makes black holes explode!

4 BLACK HOLES

Captain's log, stardate... hum... what is the date?

Dunno...

BLACK HOLES ARE PART OF THE FOLK-LORE OF 20TH CENTURY SCIENCE - THE NAME WAS ONLY FIRST USED...

Does anything work on this ship?!

THE DATE?

IN AN ASTRONOMICAL CONTEXT IN 1968 (BY JOHN WHEELER OF PRINCETON UNIVERSITY) & THE POPULAR IMAGE OF A BLACK HOLE IS OF...

- ASK for the date, & you get that poxy computer's standard lecture...

A SUPERDENSE OBJECT IN WHICH UNIMAGINABLE FORCES ARE AT WORK, WARPING TIME & SPACE

Oh black holes!

BUT THE FIRST DESCRIPTION OF WHAT WE WOULD NOW CALL AN ASTRONOMICAL BLACK HOLE WAS MADE BY THE BRITISH PIONEER JOHN MITCHELL 200 YEARS AGO...

...& can it be re-programmed?

...BEFORE WHEELER COINED THE NAME, IN 1967. & ALTHOUGH SOME BLACK HOLES ARE SEETHING, SUPERDENSE OBJECTS, SOME MAY BE AS ORDINARY IN MANY WAYS, AS WATER OR...

I've heard it more times than I've had irradiated dinners...

THE AIR THAT WE BREATHE. GIVEN ENOUGH WATER, YOU COULD MAKE A BLACK HOLE, WHICH IS MORE OR LESS WHAT MITCHELL REALISED IN THE 18TH CENTURY...

'...in the 18th century...' - hah!

Oh, I dunno... it's kinda comforting...

IN MITCHELL'S DAY, ASTRONOMERS HAD ALREADY KNOWN FOR 100 YEARS (FROM OBSERVATIONS OF THE MOONS OF JUPITER) THAT LIGHT TRAVELS AT A FINITE SPEED

...in a funny sort of way...

NEWTON'S LAWS, WHICH DESCRIBE HOW PLANETS & MOONS MOVE IN THEIR ORBITS, PROVIDED AN UNDERSTANDING OF VELOCITY...

:Sigh: 'These are the voyages of the Starship Chicken-Shack...

THAT IF A PLANET OR STAR HAS A CERTAIN MASS, THEN ANY OBJECT FIRED UPWARDS FROM ITS SURFACE...

...our mission... to boldly go...'

MUST BE MOVING AT A CERTAIN SPEED IN ORDER TO ESCAPE FROM THE PLANET'S GRAVITY.

Oh, sod this...

NEWTON'S LAWS ALSO TELL US THAT EVEN IF THE DENSITY OF AN OBJECT STAYS THE SAME...

Isn't there anything on the subspace videoband?

IF ITS SIZE IS INCREASED BY ADDING MORE MATTER - THE ESCAPE VELOCITY INCREASES...

'The Search for Spock...'

MITCHELL POINTED OUT THAT IF THE SUN WERE 500 TIMES BIGGER, BUT HAD THE SAME DENSITY...

'...the Escape Velocity would be bigger than the Speed of Light...'

Tch... seen it...

THANK YOU, JUNIOR CHICKEN. - NOT EVEN LIGHT COULD ESCAPE FROM THE HUGE OBJECT, WHICH WOULD BE INVISIBLE TO ANYBODY OUTSIDE IT...

Thank you, Ron! Anyway - what's the point of watching...

...science fiction?

...IT WOULD BE A DARK STAR EQUIVALENT TO 100,000,000 SUNS PACKED ALONGSIDE EACH OTHER IN A HUGE SPHERE LIKE A BAG FULL OF MARBLES...

-We are Science fiction! -I mean... creatures with pointed ears...

Ahem!

BUT THE AVERAGE DENSITY OF THE **WHOLE** SUN IS ONLY A LITTLE OVER A **QUARTER** OF THE DENSITY OF THE **EARTH**...

YOU REALLY COULD MAKE A BLACK HOLE OUT OF WATER OR MARBLES, IF YOU HAD **ENOUGH**...

18TH CENTURY PIONEERS IMAGINED LIGHT BEING **SLOWED DOWN** AS IT STRUGGLED TO **ESCAPE** FROM A DARK STAR...

EINSTEIN SHOWED THAT LIGHT ALWAYS TRAVELLED AT THE SAME SPEED - BUT HIS GENERAL RELATIVITY ALSO EXPLAINED HOW, EVEN SO, **GRAVITY** COULD **TRAP LIGHT** IN A BLACK HOLE.

Little green men, then...

OR EVEN **TV** DINNERS

HI!

...it's all **real life!**

Yeah... they were really **helpful** when the **starter motor** packed up on **Bageland 7**...

Gimme a re-run of **Crossroads!** -Now that's scary!

IF YOU IMAGINE THE GRAVITY OF A STAR GETTING STRONGER & **STRONGER** -

:gulp:

-THE LIGHT THAT ESCAPES IS ALWAYS **MOVING** AT THE SPEED OF LIGHT, BUT IT IS INCREASINGLY **REDSHIFTED**.

HOLE

THE WAVELENGTH OF THE LIGHT IS **STRETCHED**, RATHER LIKE THE WAY LIGHT IS STRETCHED IN THE EXPANDING UNIVERSE.

STRETCHED - REDSHIFTED LIGHT HAS **LESS ENERGY**. ITS ENERGY IS **USED UP** CLIMBING THE GRAVITATIONAL **HILL** OUT OF THE STAR...

:PANT:

:GASP:

Very droll, Ron...

THE POINT WHERE THE STAR **BECOMES** A BLACK HOLE CORRESPONDS TO GRAVITY JUST STRONG **ENOUGH**...

THAT IT USES UP **ALL** OF THE ENERGY IN THE LIGHT TRYING TO **ESCAPE**...

SO **NOTHING** ESCAPES. BUT THAT NOTHING IS, OF COURSE, STILL **MOVING** AT THE SPEED OF LIGHT.

NOTHING CAN ESCAPE FROM EVEN A **LOW-DENSITY** BLACK HOLE.

RELATIVITY **EXPLAINS** THIS IN TERMS OF **WARPED SPACE-TIME**...

Put that **light** out!

Which **reminds** me... I saw your **quarters** this morning...

...**Sort** 'em **out!**

THE GRAVITY OF A BLACK HOLE **BENDS SPACE AROUND ITSELF**, MAKING IT **CLOSED**.

FWOOSH

EVEN IF THE BEND IS VERY **GRADUAL**, IT IS STILL CLOSED. THIS IS **EXACTLY** THE SAME AS THE WAY THE **WHOLE UNIVERSE** MAY BE CLOSED...

Z

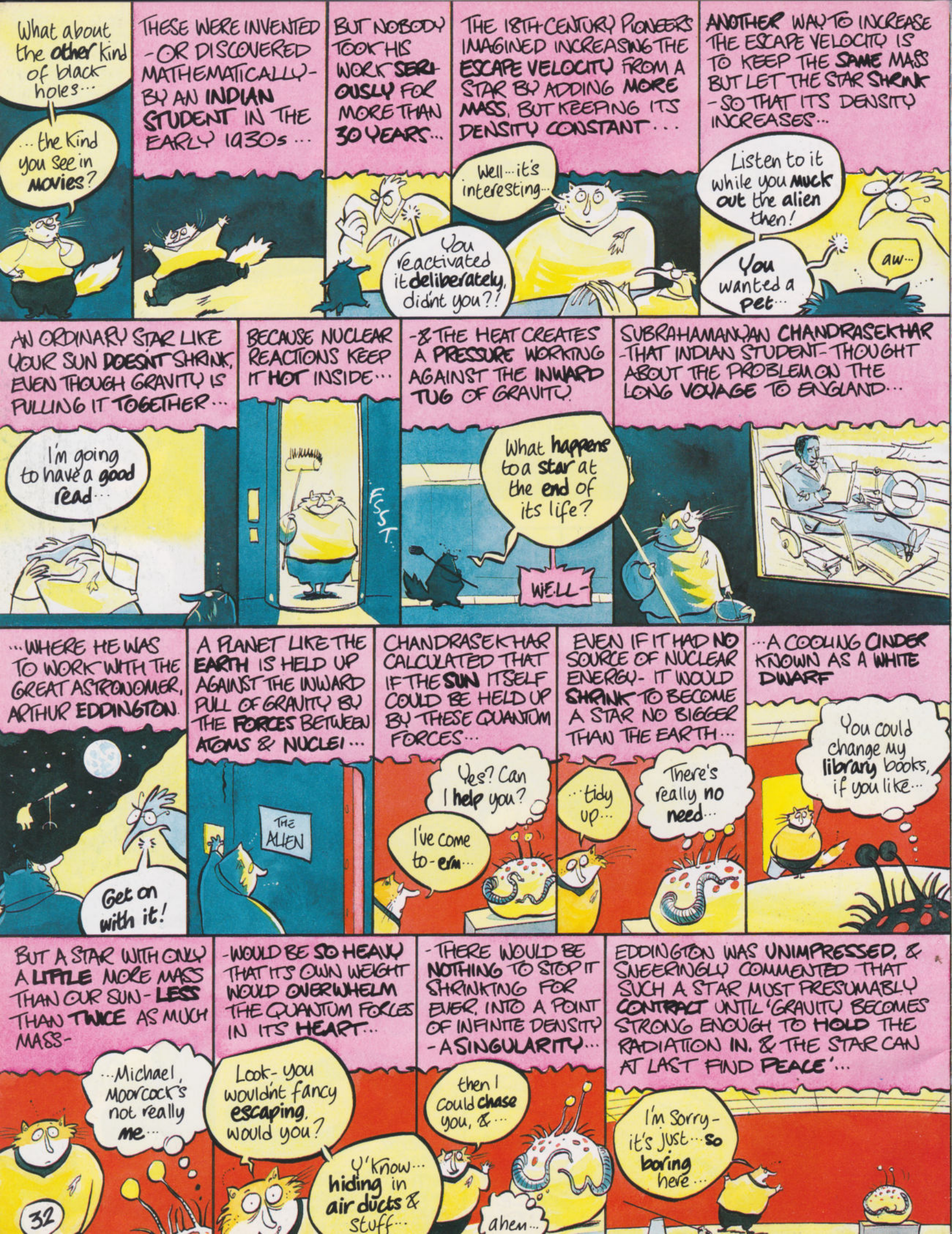
OUTDOOR RUNNING TRACK HAS **GENTLE** BENDS...

BLACK HOLES ARE **MINI-UNIVERSES**, & **YOUR UNIVERSE ITSELF** MAY BE A BLACK HOLE...

INDOOR TRACK WITH **TIGHT** BENDS - ONE IS BIGGER THAN ANOTHER, BUT **BOTH** ARE CLOSED LOOPS.

YOU MAY BE LIVING INSIDE A BLACK HOLE & **NEVER** HAVE **NOTICED**.

Can't say as I **ever** have.


What about the other kind of black holes...
...the kind you see in movies?
THESE WERE INVENTED -OR DISCOVERED MATHEMATICALLY- BY AN INDIAN STUDENT IN THE EARLY 1930s...
BUT NOBODY TOOK HIS WORK SERIOUSLY FOR MORE THAN 30 YEARS...
You reactivated it deliberately, didn't you?!
THE 18TH-CENTURY PIONEERS IMAGINED INCREASING THE ESCAPE VELOCITY FROM A STAR BY ADDING MORE MASS, BUT KEEPING ITS DENSITY CONSTANT...
Well... it's interesting...
ANOTHER WAY TO INCREASE THE ESCAPE VELOCITY IS TO KEEP THE SAME MASS BUT LET THE STAR SHRINK -SO THAT ITS DENSITY INCREASES...
Listen to it while you muck out the alien then!
You wanted a pet...
aw...
AN ORDINARY STAR LIKE YOUR SUN DOESN'T SHRINK, EVEN THOUGH GRAVITY IS PULLING IT TOGETHER...
I'm going to have a good read...
BECAUSE NUCLEAR REACTIONS KEEP IT HOT INSIDE...
FSSST
-& THE HEAT CREATES A PRESSURE WORKING AGAINST THE INWARD TUG OF GRAVITY.
What happens to a star at the end of its life?
WE'LL-
SUBRAHAMANYAN CHANDRASEKHAR -THAT INDIAN STUDENT- THOUGHT ABOUT THE PROBLEM ON THE LONG VOYAGE TO ENGLAND...
...WHERE HE WAS TO WORK WITH THE GREAT ASTRONOMER, ARTHUR EDDINGTON.
Get on with it!
A PLANET LIKE THE EARTH IS HELD UP AGAINST THE INWARD PULL OF GRAVITY BY THE FORCES BETWEEN ATOMS & NUCLEI...
THE ALIEN
CHANDRASEKHAR CALCULATED THAT IF THE SUN ITSELF COULD BE HELD UP BY THESE QUANTUM FORCES...
Yes? Can I help you?
I've come to- erm...
EVEN IF IT HAD NO SOURCE OF NUCLEAR ENERGY- IT WOULD SHRINK TO BECOME A STAR NO BIGGER THAN THE EARTH...
...tidy up...
There's really no need...
...A COOLING CINDER KNOWN AS A WHITE DWARF
You could change my library books, if you like...
BUT A STAR WITH ONLY A LITTLE MORE MASS THAN OUR SUN- LESS THAN TWICE AS MUCH MASS-
...Michael, Moorcock's not really me...
32
-WOULD BE SO HEAVY THAT ITS OWN WEIGHT WOULD OVERWHELM THE QUANTUM FORCES IN ITS HEART...
Look- you wouldn't fancy escaping, would you?
Y'know... hiding in air ducts & stuff...
-THERE WOULD BE NOTHING TO STOP IT SHRINKING FOR EVER, INTO A POINT OF INFINITE DENSITY -A SINGULARITY...
then I could chase you, &...
ahem...
EDDINGTON WAS UNIMPRESSED, & SNEERINGLY COMMENTED THAT SUCH A STAR MUST PRESUMABLY CONTRACT UNTIL 'GRAVITY BECOMES STRONG ENOUGH TO HOLD THE RADIATION IN, & THE STAR CAN AT LAST FIND PEACE'...
I'm sorry- it's just... so boring here...

HE MEANT THE COMMENT SARCASTICALLY - BUT NOW, THAT'S EXACTLY WHAT ASTRONOMERS THINK HAPPENS TO STARS - LEFT WITH MORE THAN ABOUT TWICE AS MUCH MASS AS OUR SUN AT THE END OF THEIR LIVES...

THE STAR SHRINKS & GRAVITY GETS STRONGER, WARPING SPACE AROUND ITSELF EVER MORE TIGHTLY UNTIL EVENTUALLY IT CUTS ITSELF OFF FROM THE REST OF THE UNIVERSE ENTIRELY.

I hear what you're saying...

...but unless you've into Soto Zen...

IT HAS BECOME A SELF-CONTAINED BLACK HOLE - A CLOSED REGION OF SPACETIME...

...I can't really help you...

rats!

FOR A PARTICULAR MASS, THERE'S A CERTAIN RADIUS AROUND THE CENTRAL SINGULARITY WHICH IS CUT OFF FROM THE OUTSIDE...

...& are we going to have the black hole lecture every time the chicken forgets the date?

OM...

(IN THE CASE OF YOUR SUN, IT WOULD HAVE TO BE SQUEEZED INTO A BALL WITH A RADIUS OF JUST 3KM TO BECOME A BLACK HOLE;

Huh! & I was going to call it Rover...

om

THE EARTH WOULD HAVE TO BE SQUEEZED EVEN SMALLER WITHIN A RADIUS OF ONE CENTIMETRE)

VIRGOAN DOLLAR

EARTH

NOTHING CAN ESCAPE FROM WITHIN THIS 'EVENT HORIZON'

Better cancel the space program...

NOTHING CAN GET OUT OF A BLACK HOLE, BUT IT STILL EXERTS A GRAVITATIONAL PULL ON THE WORLD OUTSIDE - & IT WILL SWALLOW UP ANYTHING THAT PASSES TOO CLOSE...

Cosmic quicksand...

SLURP

AS IT DOES SO, ITS MASS INCREASES & ITS EVENT HORIZON GROWS OUTWARD...

BUT THIS KIND OF STELLAR MASS BLACK HOLE IS A MESSY EATER...

Pardon...

MATERIAL FALLING INTO THE HOLE IS RIPPED APART BY INTENSE TIDAL FORCES & FORMS A SWIRLING DISC OF MATTER SLOWLY FUNNELING ACROSS THE EVENT HORIZON...

IN THE DISC, GRAVITATIONAL ENERGY IS CONVERTED INTO HEAT AS ATOMS BASH INTO ONE ANOTHER -

- LIKE THE M25 ON A GOOD DAY -

SO ALTHOUGH THE BLACK HOLE ITSELF IS INVISIBLE, THE REGION JUST OUTSIDE IT MAY BE RADIATING ENERGY

- VIOLENTLY ACROSS THE ELECTRO-MAGNETIC SPECTRUM, FROM X RAYS & GAMMA RAYS TO RADIO WAVES...

Hi there, rock freaks! Let's get all 3 heads banging to... Betelguse Thrash! Yeah!

IN THE 1960S & 1970S ASTRONAUTS IDENTIFIED MANY INTENSE SOURCES OF ENERGY IN THE UNIVERSE, PINPOINTS ON THE SKY THAT BLAST OUT X RAYS INTO SPACE...

HEY!

THE ONLY WAY TO EXPLAIN THESE WAS TO REVIVE CHANDRASEKHAR'S 30-YEAR-OLD THEORY.

MANY OF THESE SOURCES OF ENERGY CAN ONLY BE SITES WHERE A BLACK HOLE OF THE KIND EDDINGTON DISMISSED AS NONSENSE

ORBITS AROUND AN ORDINARY STAR, STRIPPING GAS FROM IT THROUGH TIDAL FORCES -

- & SWALLOWING IT IN A VIOLENT DISPLAY OF STELLAR CANNIBALISM...

I need some air! - Or space, anyway...

...AS WELL AS THESE **ORDINARY** BLACK HOLES, THERE ARE ALSO **MINI** & **MAXI** VARIETIES...

ALMOST EXACTLY LIKE THE ONES MITCHELL ENVISAGED MORE THAN **200** YEARS AGO.

MANY GALAXIES SHINE VERY BRIGHTLY IN THEIR CENTRAL **CORES**, RADIATING NOT JUST **VISIBLE** LIGHT, BUT **RADIO WAVES**, & SHOWING **OTHER** SIGNS OF DISTURBANCE...

Um... **Actually**, **Ron**, I was hoping for a **quiet**, '**emptiness of space**' type breath of air...

SORRY, LT. ALEXIS... **PROGRAMS** ARE THERE TO BE **PLAYED**...

CS-1

IN SOME CASES, THE BRIGHT **NUCLEUS** OF A GALAXY **FAR** OUTSHINES THE LIGHT OF **ALL** THE HUNDRED BILLION STARS THAT SURROUND IT **PUT TOGETHER**...

SUCH BRIGHT GALACTIC NUCLEI CAN BE SEEN ACROSS **VAST DISTANCES** OF **SPACE**...

SO THAT THE LIGHT YOU SEE THEM BY IS ENORMOUSLY **REDSHIFTED** IN THE EXPANDING UNIVERSE.

THE STARS OF THE GALAXY ARE TOO **FAINT** TO BE SEEN SO FAR AWAY-

-BUT THE CENTRAL **CORE** SHINES SO BRIGHTLY THAT WHEN IT IS PHOTOGRAPHED BY TELESCOPES ON EARTH, IT LOOKS LIKE A **SINGLE STAR**.

SUCH OBJECTS ARE KNOWN AS QUASISTELLAR OBJECTS OR **QUASARS**.

Now **look**, Ron...

BONK

CS-1

THE REDSHIFT OF A QUASAR REVEALS ITS **DISTANCE**, BECAUSE THE REDSHIFT IS **BIGGER** THE **FURTHER** LIGHT TRAVELS ACROSS **EXPANDING SPACE**...

THE **DISTANCE** TELLS ASTRONOMERS HOW BRIGHT A QUASAR MUST BE IN ORDER TO BE VISIBLE ON **EARTH**.

IN ORDER TO SHINE SO BRIGHT, THE POWERHOUSE OF A QUASAR IS **SWALLOWING UP** ONE OR TWO TIMES THE MASS OF YOUR SUN EVERY **YEAR**-

-**EATING** WHOLE STARS, NOT JUST STRIPPING BITS **OFF** THEM...

& CONVERTING MATTER INTO ENERGY IN LINE WITH EINSTEIN'S EQUATION $E=mc^2$. THE **GRAVITY** OF A BLACK HOLE PROVIDES THE **MOST** EFFICIENT WAY TO CONVERT **MASS** TO **ENERGY** LIKE THIS...

Hey - as you're **out there** - check out the **phasar tubes**...

& bring the **milk** in

THE MASS YOU **NEED** FOR THE BLACK HOLE TO **EXPLAIN** THE **POWER** PRODUCED BY A TYPICAL QUASAR IS ABOUT 100,000,000 TIMES THE MASS OF YOUR SUN - ALMOST **EXACTLY** THE KIND OF BLACK HOLE **MITCHELL** IMAGINED.

& I'm **sick to death** of '**put** the **cat out**' jokes...

SUCH A BLACK HOLE DOES NOT INVOLVE ANYTHING GETTING **SQUEEZED DOWN** TO THE POINT WHERE QUANTUM FORCES ARE **OVERWHELMED** BY GRAVITY.

(AT LEAST, NOT TO **START** WITH, BUT ONCE IT FORMS, MATTER WILL **INVARIABLY** SETTLE INTO THE **CENTRE**)

IT COULD ARISE JUST BECAUSE **TOO MANY** STARS GOT **TOO CLOSE TOGETHER** IN THE CORE OF THE GALAXY...

...SORTA COSMIC **OSCAR** SHOW...

I.S.I.

:AHEM:- A HUNDRED MILLION SOLAR MASSES **SOUNDS** A **LOT**...

-BUT COMPARE IT WITH THE **MASS** OF THE **WHOLE GALAXY** - WHICH IS AROUND A HUNDRED BILLION SOLAR MASSES

THE **CENTRAL** BLACK HOLE THAT **POWERS** A QUASAR REPRESENTS JUST **0·1%** OF THE MASS AVAILABLE IN THE SURROUNDING GALAXY...

THE **EVENT HORIZON** OF SUCH A BLACK HOLE IS NO BIGGER ACROSS THAN YOUR **SOLAR SYSTEM**, EVEN THOUGH IT CONTAINS THE MASS OF **100,000,000** SUNS

...& ON THE EVENT HORIZON **ITSELF** THE DENSITY IS NO GREATER...

I.S.I.

THAN THE DENSITY OF **WATER** THAT COMES OUT OF A **TAP** IN YOUR **KITCHEN**

-IF YOU **HAD** SUCH A THING, LIEUTENANT-

AN INTREPID ASTRONAUT COULD **PILOT** A SPACECRAFT **ACROSS** THE EVENT HORIZON WITHOUT DIFFICULTY & STUDY WHAT **HAPPENS INSIDE** A **BLACK HOLE**.

Well, as **long as it's not us**...

It's **not**, is it?

UNFORTUNATELY, THE SPACEFARER COULD **NEVER ESCAPE**, OR EVEN SEND A MESSAGE BACK TO THE OUTSIDE WORLD TO **REPORT** THOSE **DISCOVERIES** TO INTERESTED ASTROPHYSICISTS...

...**IS** it?

& WITHIN A FEW HOURS, BOTH COSMONAUT & SPACE CRAFT WOULD FIRST BE **STRETCHED OUT** BY TIDAL FORCES - LIKE **TOOTHPASTE** BEING SQUEEZED FROM A **TUBE**...

& THEN **CRUSHED** INTO A STATE OF **ZERO VOLUME** & **INFINITE DENSITY** IN THE **CENTRAL SINGULARITY**

IS IT?!

COSY, NO?

SCREAM!

?!

I've just had the strangest dream...

SCREAM!

I thought this was a pretty good outfit for the para-scientists ball...

ONE OF THE PEOPLE WHO PROVED THAT BLACK HOLES MUST CONTAIN A SINGULARITY -A POINT WHERE OUR UNDERSTANDING OF SPACE, TIME & PHYSICS BREAKS DOWN...

BOFFIN-AM BREAKFAST CHANNEL

So early...

WAS STEPHEN HAWKING OF THE UNIVERSITY OF CAMBRIDGE

...BUT HE ALSO DID SOMETHING EVEN MORE CLEVER... HE COMBINED GENERAL RELATIVITY, QUANTUM THEORY & THERMODYNAMICS IN ONE PACKAGE...

...LINKING THE BEHAVIOUR OF BLACK HOLES TO THE NATURE OF TIME, & PROVING THAT IN SOME CASES AT LEAST -

Black hdes ain't so black!

IN PRINCIPLE, ANY AMOUNT OF MATTER, NO MATTER HOW SMALL, COULD MAKE A BLACK HOLE IF YOU SQUEEZED IT HARD ENOUGH...

PRODUCING SUCH AN INTENSE GRAVITATIONAL FIELD THAT IT WARPED SPACE-TIME AROUND ITSELF

IN FACT, EVEN SUPERMAN CANNOT SQUEEZE THAT HARD-

Aw, nuts! Diamonds again!

IT'S IMPOSSIBLE TO IMAGINE SQUEEZING THE EARTH DOWN INTO A SPHERE 1CM ACROSS - A MASS OF 1 KILOGRAM WOULD CORRESPOND TO A BLACK HOLE ONLY 1 BILLIONTH AS BIG AS AN ATOM...

Please!

THE LESS MASS AN OBJECT HAS, THE HARDER IT IS TO MAKE IT INTO A BLACK HOLE...

BUT ONE PLACE WHERE MATTER WAS REALLY SQUEEZED HARD WAS IN THE BIG BANG ITSELF.

ANYTHING COULD HAVE COME OUT OF THE SUPER-DENSITY THAT EXISTED NEAR THE SINGULARITY IN WHICH OUR UNIVERSE WAS BORN...

INCLUDING MINI BLACK HOLES WITH A MASS OF A FEW KILOGRAMS CONTAINED WITHIN EVENT HORIZONS MUCH SMALLER THAN ATOMS.

YOU MIGHT THINK THAT NOTHING WOULD BE HARDER TO DETECT - BUT HAWKING PROVED THAT WRONG IN THE 1970s...

GENERAL RELATIVITY COMES IN, BECAUSE GRAVITY IS INCLUDED...

THERMODYNAMICS COMES IN, BECAUSE HAWKING SHOWED THAT EVERY BLACK HOLE HAS A TEMPERATURE...

-& THAT IT KNOWS WHICH WAY TIME FLOWS.

Bacon yes- eggs no- I know it's illogical...

sssssss

QUANTUM PHYSICS COMES IN, BECAUSE IT TELLS YOU HOW TO MAKE PARTICLES OUT OF NOTHING AT ALL...

OK- I'll demonstrate...

MAKING MATTER OUT OF ENERGY IS EASY - IF THERE'S ENOUGH E AROUND, YOU GET mc^2 - THE ONLY THING NATURE HAS TO WORRY ABOUT IS THAT EACH PARTICLE THAT IS MADE IS ACCOMPANIED BY ITS ANTIPARTICLE - A KIND OF MIRROR IMAGE...

EVERY TIME AN ELECTRON IS MADE OUT OF PURE ENERGY, IT IS ACCOMPANIED BY A PARTICLE CALLED A POSITRON
...& WHEN A POSITRON MEETS AN ELECTRON THEY ANNIHILATE EACH OTHER, TURNING mc² BACK INTO E...
CHOMP
See?
QUANTUM UNCERTAINTY LETS YOU DO THIS EVEN IF THERE WASN'T ANY E AROUND IN THE FIRST PLACE...
There aren't any mushrooms either, now...
LIKE POSITION & MOMENTUM, ENERGY & TIME SHARE A SET AMOUNT OF UNCERTAINTY...
H'mm...
H'mm...
IN EFFECT, UNCERTAINTY SAYS THAT A PAIR OF PARTICLES CAN APPEAR OUT OF NOTHING AT ALL-
So can a hungry chicken...
SNATCH
-PROVIDED THAT THEY ANNIHILATE AGAIN BEFORE THE UNIVERSE NOTICES...
Too little, too late...
'EMPTY' SPACE IS REGARDED BY PHYSICISTS AS A SEETHING MAELSTROM OF ACTIVITY IN WHICH PARTICLES ARE CONSTANTLY POPPING INTO EXISTENCE...
..ANNIHILATING & DISAPPEARING, ALL IN THE SPAN OF ABOUT 0·0000 0000000000 000001 SECONDS (10⁻²⁰SEC)
KWANTUM KRISPIES
BUT WHAT HAPPENS TO SUCH A PAIR OF PARTICLES THAT POP INTO EXISTENCE RIGHT ON THE EDGE OF A BLACK HOLE EVENT HORIZON?
OK. You be the black hole...
THERE, IN THE SPLIT SECOND THAT THE PAIR EXISTS, ONE OF THE PARTICLES MIGHT BE CAPTURED BY THE BLACK HOLE- LEAVING THE OTHER NOTHING TO ANNIHILATE WITH...
SWOOP
...So it scoots off into the Universe at large...
THE MASS-ENERGY OF THE 'NEW' PARTICLE HAD COME, HAWKING SHOWED, FROM THE MASS OF THE BLACK HOLE ITSELF...
Very funny...
PARTICLES BOIL OFF FROM THE SURFACE OF THE BLACK HOLE ALL THE TIME, MAKING IT HOT
-WHILE THE HOLE ITSELF LOSES MASS & THE EVENT HORIZON SHRINKS INWARD
SKRITCH
SKRATCH
FOR A LARGE HOLE, THIS HAS NO SIGNIFICANT EFFECT, BECAUSE IT GOBBLES UP MATTER FASTER THAN PARTICLES BOIL OFF...
BUT FOR A MINI BLACK HOLE, EATING THINGS IS DIFFICULT
Huh...
SO THIS EVAPORATION REALLY DOES MAKE IT SHRINK UNTIL IT VANISHES IN A PUFF OF GAMMA RAYS...
Look- let's not take this too far!
UNFORTUNATELY, ALTHOUGH ASTRONOMERS HAVE DETECTED X RAY PULSES, NOBODY HAS HAD THE NERVE TO CLAIM THEY MAY BE THE DEATH THROES OF MINI BLACK HOLES...
HAWKING HAD DISCOVERED A NEW VERSION OF THE ARROW OF TIME. THE FUTURE IS THE DIRECTION IN WHICH BLACK HOLES EVAPORATE...
Sort've puts you off pension plans...
AS AN ENCORE, IN THE 1980s, HE WAS CLOSELY INVOLVED IN IMPROVING OUR UNDERSTANDING OF HOW TIME BEGAN...
Black holes were fitted with alarm clocks?...
BREAKFAST WITH BOFFINS!

5 The BIRTH of TIME

MIME VERSION

IF WE WIND THE EXPANSION OF THE UNIVERSE BACKWARDS, WE CAN CALCULATE THAT THE UNIVERSE WAS BORN—

I feel silly...

IN A STATE OF INFINITE DENSITY & TEMPERATURE 15 BILLION YEARS AGO. THAT WAS THE MOMENT WHEN TIME BEGAN.

IT WAS A SINGULARITY, EXACTLY LIKE THE SINGULARITIES THAT EXIST AT THE HEARTS OF BLACK HOLES... THE EQUATIONS THAT DESCRIBE THE EXPANDING UNIVERSE ARE EXACTLY THE EQUATIONS THAT DESCRIBE COLLAPSING BLACK HOLES BUT RUNNING IN THE OPPOSITE DIRECTION...

BUT WE STILL CANNOT DEAL WITH INFINITIES IN THE EQUATIONS. HOW FAR BACK CAN WE PUSH OUR UNDERSTANDING OF PHYSICS?

THE MOST EXTREME DENSITY OF MATTER WE KNOW TODAY LIES IN THE NUCLEUS OF EVERY ATOM...

NUCLEUS

ATOM

NUCLEAR MATTER HAS A DENSITY OF 10^{14} GRAMS PER CUBIC CENTIMETRE, ONE HUNDRED THOUSAND BILLION TIMES THE DENSITY OF WATER, & PHYSICISTS RECKON THEY UNDERSTAND NUCLEI PRETTY WELL...

No... really?

IF WE WIND THE UNIVERSE BACK TO THE POINT WHERE EVERYTHING WAS PACKED TOGETHER AT THIS DENSITY, THE EQUATIONS SHOULD STILL WORK

THEN, THE UNIVERSE HAD A TEMPERATURE OF A THOUSAND BILLION DEGREES & THE TIME WAS ONE TEN THOUSANDTH (0·0001) OF A SECOND AFTER THE MOMENT OF CREATION

EEEEK!

JUST AS GAMOW WAS HAPPY WITH HIS THEORY THAT EXPLAINED WHERE 99% OF THE MATTER IN THE UNIVERSE CAME FROM,

EVERYTHING EXCEPT THE HARD BITS...

IN THE 1960s COSMOLOGISTS WERE HAPPY TO BE ABLE TO EXPLAIN EVERYTHING THAT HAD HAPPENED TO THE UNIVERSE AFTER t=0·0001 SEC, WITHOUT WORRYING TOO MUCH ABOUT WHAT HAPPENED BEFORE THAT, THE DESCRIPTION OF EVERYTHING SINCE t=0·0001 SEC (ACTUALLY, A BIT LATER...)

-BECAME KNOWN AS THE 'STANDARD MODEL' OF COSMOLOGY.

The Little 'Standard Model' Outfit

IT WAS IMMORTALISED IN 1976 BY AMERICAN PHYSICIST STEPHEN WEINBERG IN A BOOK CALLED 'THE FIRST THREE MINUTES'

THE 1ST 3 MINUTES

THE TITLE WAS A CHEAT. HIS ACCOUNT OF THE CREATION STARTED AT t=0·01 SEC, & ENDED 3 MINUTES, 46 SECS LATER...

THE 1ST 3 MINUTES & A BIT

IT EXPLAINED HOW A SUPERDENSE FIREBALL OF RADIATION & MATTER AT A TEMPERATURE OF 100 BILLION DEGREES WAS TRANSFORMED AS IT COOLED...

...INTO A MIXTURE OF 75% HYDROGEN & 25% HELIUM, WITH THE REMAINING RADIATION LEFT TO FADE AWAY & BECOME THE WEAK HISS OF THE COSMIC BACKGROUND WE KNOW TODAY...

H

He

THE TRIUMPH OF THE STANDARD MODEL IS THAT IT 'PREDICTS' THIS RATIO, ¾ HYDROGEN & ¼ HELIUM...

Just a knack...

WHICH IS THE MIXTURE WE ACTUALLY SEE IN VERY OLD STARS...

Ronald

FROM ESTIMATES OF HOW FAST THE UNIVERSE IS EXPANDING...

t (TIME) = 0·0001
T (TEMPERATURE) = 1000 BILLION K
ρ (DENSITY) = NUCLEAR DENSITY

t = 0·01 SEC
T = 30 K
D = 30 MILLION
× WATER

t = 0·001 S
T = 300 BILLION K
D = A BILLION
× WATER

IT STARTS WITH CONDITIONS SO **EXTREME** THAT THE UNIVERSE WAS A **SEA OF PROTONS & NEUTRONS** -

- CONSTANTLY BEING **BOMBARDED** BY ENERGETIC PULSES OF **RADIATION** (PHOTONS)

& WITH PROTONS **CHANGING** INTO NEUTRONS & NEUTRONS CHANGING INTO PROTONS ALL THE TIME...

IT EXPLAINS HOW, WHEN THINGS **COOLED DOWN**, & ALL THIS SWITCHING AROUND STOPPED -

- JUST **ENOUGH** OF THESE PROTONS & NEUTRONS COMBINED TO FORM **HELIUM** NUCLEI - WHILE THE REST WERE LEFT AS PROTONS, WHICH ARE **HYDROGEN** NUCLEI...

& BECAME **ATOMS**.

t = 15 BILLION YEARS AGO
T = 2.7 K
D = 1 ATOM FOR EVERY 1000 LITRES OF SPACE, + 500 PHOTONS IN EVERY CUBIC CENTIMETRE OF SPACE

NOW

t = 700,000 YEARS
T = 4000 K
ELECTRONS & NUCLEI **COMBINE** TO FORM **ATOMS**; UNIVERSE NOW **COOLER** THAN SURFACE OF THE **SUN**; **10 MILLION** ATOMS IN EVERY **LITRE** OF SPACE...

t = 34 MIN. 40 SEC
T = 300 MILLION K
D = WATER

t = 3 MIN. 46 SEC
T = 900 MILLION K
HYDROGEN / HELIUM RATIO SET...

t = 3 MIN. 2 SEC
T = 1 BILLION K
70 x TEMPERATURE AT HEART OF SUN

t = 14 SEC
T = 3a K
HELIUM NUCLEI START TO FORM

t = 1 SEC
T = 10⁹ K

90,000

AS THE UNIVERSE COOLED EVEN **MORE**, THESE NUCLEI **CAPTURED** ELECTRONS FROM THEIR **SURROUNDINGS**

IF THE UNIVERSE HAD BEEN EXPANDING JUST A LITTLE BIT **FASTER** - OR A LITTLE BIT **SLOWER**...

Hurry it up!

UNIVERSE

hnnnft!

UNIVERSE

or **hyper-ventilated**...

...15 BILLION YEARS AGO; THEN THE **BIG BANG** FIREBALL WOULD HAVE EITHER PRODUCED **ALL** HELIUM OR **ALMOST ALL** HYDROGEN...

IN **EITHER** CASE: STARS WOULD BE VERY **DIFFERENT** IN **APPEARANCE** (& WE MIGHT NOT BE HERE)

THE RATE AT WHICH THE UNIVERSE IS **EXPANDING** IS **TIED** TO THE RATIO OF THREE TIMES AS MUCH HYDROGEN TO HELIUM IN **OLD STARS**...

OK-OK...

Lili Marlene

IT IS ALSO TIED TO THE AMOUNT OF **RADIATION** THERE WAS IN THE **FIREBALL**. FOR **EVERY** PROTON OR NEUTRON (**BARYON**) THERE IS IN THE UNIVERSE

A **BARYON**

THERE MUST BE A **BILLION** (10^9) **PHOTONS** OF RADIATION - BUT THE PHOTONS ARE SPREAD OUT EVENLY THROUGH THE ENTIRE UNIVERSE.

sigh

how embarrassing...

AUDIENCE PARTICIPATION BIT

EVERYBODY OUT THERE HOLD UP A LIGHTED MATCH

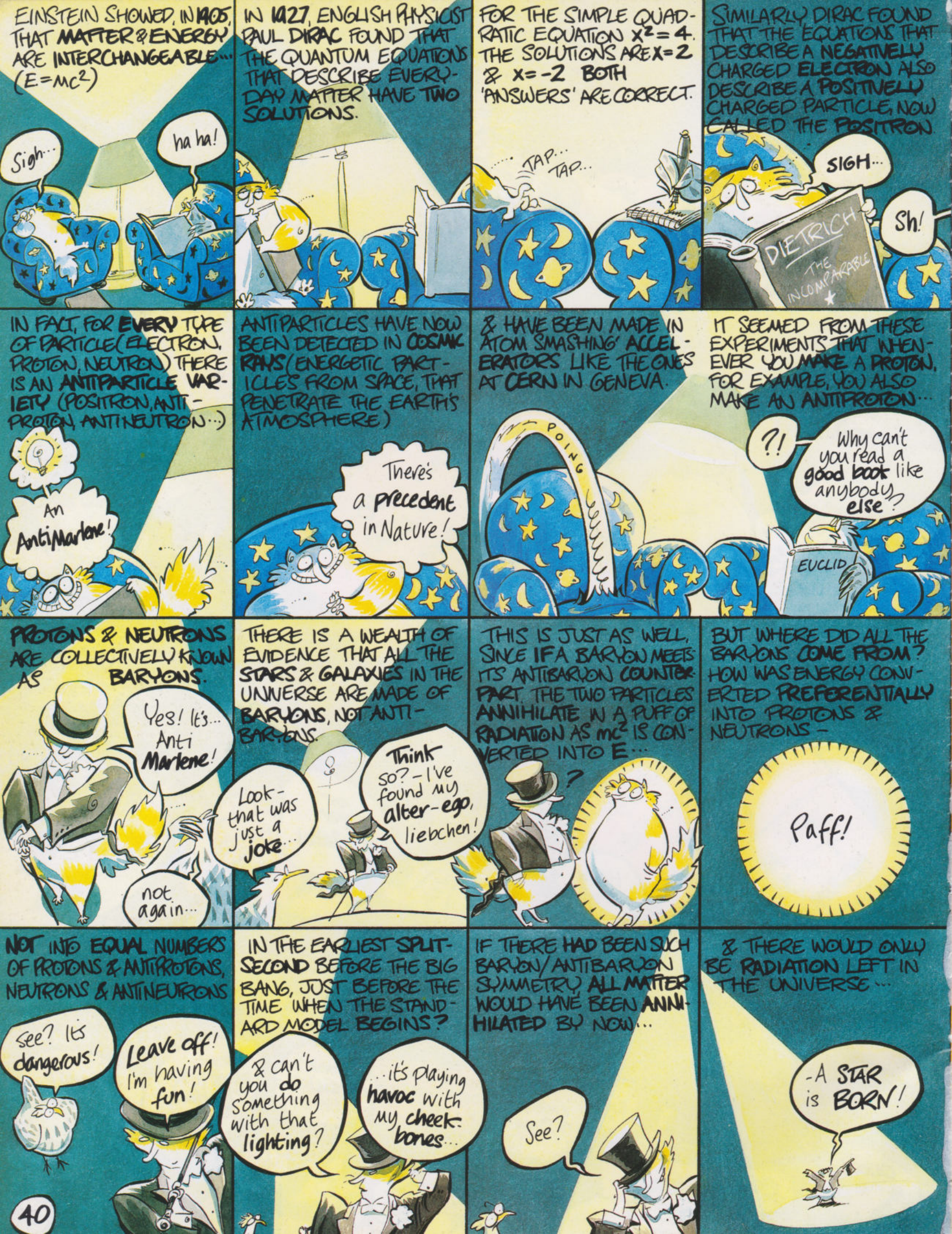
WHILE THE BARYONS ARE **GATHERED** IN **LUMPS** CALLED **STARS** & **GALAXIES** (& **PLANETS** & **PEOPLE**).

Look! I'm **sick** of this!

I don't **want** to be the **Horsehead** Nebula!

BUT WHAT THE STANDARD MODEL **CANNOT** EXPLAIN IS WHY THERE **WAS** ANY MATTER AROUND **AT ALL** AT t=0.01 SEC...

& I can't say I **blame** it!


EINSTEIN SHOWED, IN 1905, THAT MATTER & ENERGY ARE INTERCHANGEABLE... ($E=mc^2$)
Sigh...
ha ha!
IN 1927, ENGLISH PHYSICIST PAUL DIRAC FOUND THAT THE QUANTUM EQUATIONS THAT DESCRIBE EVERY-DAY MATTER HAVE TWO SOLUTIONS.
FOR THE SIMPLE QUADRATIC EQUATION $x^2=4$. THE SOLUTIONS ARE $x=2$ & $x=-2$ BOTH 'ANSWERS' ARE CORRECT.
TAP... TAP...
SIMILARLY DIRAC FOUND THAT THE EQUATIONS THAT DESCRIBE A NEGATIVELY CHARGED ELECTRON ALSO DESCRIBE A POSITIVELY CHARGED PARTICLE, NOW CALLED THE POSITRON
SIGH...
DIETRICH THE INCOMPARABLE
Sh!
IN FACT, FOR EVERY TYPE OF PARTICLE (ELECTRON, PROTON, NEUTRON) THERE IS AN ANTIPARTICLE VARIETY (POSITRON, ANTI-PROTON, ANTINEUTRON...)
An Anti Marlene!
ANTIPARTICLES HAVE NOW BEEN DETECTED IN COSMIC RAYS (ENERGETIC PARTICLES FROM SPACE, THAT PENETRATE THE EARTH'S ATMOSPHERE)
There's a precedent in Nature!
& HAVE BEEN MADE IN ATOM SMASHING ACCELERATORS LIKE THE ONES AT CERN IN GENEVA.
POING
IT SEEMED FROM THESE EXPERIMENTS THAT WHENEVER YOU MAKE A PROTON, FOR EXAMPLE, YOU ALSO MAKE AN ANTIPROTON...
?!
Why can't you read a good book like anybody else?
EUCLID
PROTONS & NEUTRONS ARE COLLECTIVELY KNOWN AS BARYONS.
Yes! It's... Anti Marlene!
not again...
THERE IS A WEALTH OF EVIDENCE THAT ALL THE STARS & GALAXIES IN THE UNIVERSE ARE MADE OF BARYONS, NOT ANTI-BARYONS.
Look - that was just a joke...
Think so? - I've found my alter-ego, liebchen!
THIS IS JUST AS WELL, SINCE IF A BARYON MEETS ITS ANTIBARYON COUNTERPART THE TWO PARTICLES ANNIHILATE IN A PUFF OF RADIATION AS mc^2 IS CONVERTED INTO E...
?
BUT WHERE DID ALL THE BARYONS COME FROM? HOW WAS ENERGY CONVERTED PREFERENTIALLY INTO PROTONS & NEUTRONS -
Paff!
NOT INTO EQUAL NUMBERS OF PROTONS & ANTIPROTONS, NEUTRONS & ANTINEUTRONS
See? It's dangerous!
Leave off! I'm having fun!
IN THE EARLIEST SPLIT-SECOND BEFORE THE BIG BANG, JUST BEFORE THE TIME WHEN THE STANDARD MODEL BEGINS?
& can't you do something with that lighting?
...it's playing havoc with my cheek-bones...
IF THERE HAD BEEN SUCH BARYON/ANTIBARYON SYMMETRY, ALL MATTER WOULD HAVE BEEN ANNIHILATED BY NOW...
See?
& THERE WOULD ONLY BE RADIATION LEFT IN THE UNIVERSE...
-A STAR is BORN!
40

THE **FIRST** PERSON TO REALISE THE **IMPORTANCE** OF THIS WAS THE SOVIET PHYSICIST ANDREI **SAKHAROV**, IN THE LATE **1960**s...

BUILDING ON **HIS** WORK, PHYSICISTS NOW THINK THEY **KNOW** WHAT **HAPPENED**.

Come back, this is **important**!

IT TURNS OUT THAT THE LAWS OF PHYSICS ARE **NOT** PERFECTLY **SYMMETRICAL**, BUT CONTAIN A **FAVOURITISM** FOR **MATTER** OVER ANTIMATTER.

!

HI!

THE FAVOURITISM IS TINY, JUST **ONE PART** IN A **BILLION**. FOR EVERY BILLION **ANTI**-BARYONS MANUFACTURED OUT OF ENERGY, THERE WILL BE A BILLION **& ONE** BARYONS...

THE IMBALANCE IS FAR TOO **SMALL** TO HAVE SHOWN UP IN EXPERIMENTS ON EARTH...

Who are **you**? **Another** Antimarlene?

BUT IT MEANS THAT IN THE COSMIC **FIREBALL** OF THE BIG BANG ITSELF, THERE WERE A **BILLION & ONE BARYONS** FOR EVERY **BILLION ANTIBARYONS**...

You **mean** you can't **tell**?

WHEN THE UNIVERSE EXPANDED & COOLED, EVERY ANTIBARYON EVENTUALLY MET ITS BARYONIC **PARTNER**...

I'm an **Antillinelli**!

...& CONVERTED INTO **ENERGY** (**ANY** PROTON WILL ANNIHILATE WITH **ANY** ANTIPROTON, NOT A **SPECIFIC** PARTNER)

Paff!

JUST **ONE** IN A BILLION BARYONS WERE LEFT- EACH ACCOMPANIED BY A **BILLION** (10^9) **PHOTONS**.

...sigh...

THE FACT THAT THERE ARE A BILLION PHOTONS OF THE COSMIC BACKGROUND RADIATION FOR **EVERY** BARYON IN THE UNIVERSE...

What good...

DEPENDS ON THE WAY THE **LAWS** OF **PHYSICS** OPERATE UNDER CONDITIONS FAR MORE **EXTREME** THAN ANY THAT EXIST IN THE UNIVERSE TODAY-

is sitting...

-BACK WHEN THE DENSITY OF THE **ENTIRE UNIVERSE** WAS GREATER THAN THE DENSITY OF THE **NUCLEUS** OF AN **ATOM**

alone in your room?

THE **ULTIMATE** TEST OF THEORIES OF PHYSICS TODAY IS NOT PROVIDED BY ATOM SMASHING EXPERIMENTS.

Come...

BUT BY COMPARING WHAT THOSE THEORIES TELL US ABOUT THE **EARLY** UNIVERSE WITH THINGS WE CAN OBSERVE **TODAY**-

...hear the music play...

-SUCH AS THE **RATIO** OF BARYONS TO PHOTONS.

Life is a **cabaret**, old chum

THE **WHOLE UNIVERSE** IS THE PHYSICIST'S LABORATORY.

Come to the **cabaret**!

If you can't **beat** em...

At the end of the 1970s, cosmologists were puzzled by several features of the Universe...

it's very, very smooth...

WE LOOK OUT IN ONE DIRECTION (USING RADIO TELESCOPES) & CAPTURE A PHOTON THAT HAS BEEN 15 BILLION YEARS ON ITS JOURNEY TO US-

ALLOWING FOR SUCH IRREGULARITIES AS GALAXIES, THE UNIVERSE LOOKS MUCH THE SAME FROM PLACE TO PLACE, & IN ANY DIRECTION YOU LOOK...

...the best way to see this is to think in terms of the cosmic background radiation

Why?

PARTICLE PHYSICS RESOLVES BOTH PUZZLES, THE WAY THAT ENERGY IS CONVERTED INTO MATTER IN THE FIRST SPLIT SECOND OF THE BIG BANG...

EACH OF THESE CHANGES RELEASES ENERGY KNOWN AS LATENT HEAT, BECAUSE THE MOLECULES IN THE WATER ARE REARRANGED IN A DIFFERENT FORM...

(...ULTIMATELY LEADING TO AN EXCESS OF ONE BARYON FOR EVERY BILLION ANTI-BARYON PAIRS) IS A KIND OF PHASE TRANSISION.

THE BEST KNOWN PHASE TRANSITIONS ARE WHEN WATER VAPOUR TURNS INTO LIQUID (CONDENSATION) OR WATER TURNING INTO ICE (FREEZING)

IN FAR LESS THAN THE BLINK OF AN EYE, A REGION OF SPACE 10^{-17} OF THE SIZE OF AN ATOM WAS INFLATED INTO A REGION THE SIZE OF A GRAPEFRUIT...

IN 10^{-33}S IT DOUBLED 10 TIMES; IN 10^{-32}S IT INCREASED IN SIZE 2^{100} TIMES, BY A FACTOR OF ABOUT 10^{50} (A ONE FOLLOWED BY 50 ZEROS)

THEN ALL THE LATENT HEAT HAD BEEN RELEASED, & THE PROCESS STOPPED...

...EVER SINCE, THE EXPANSION OF THE UNIVERSE HAS BEEN SLOWING DOWN...

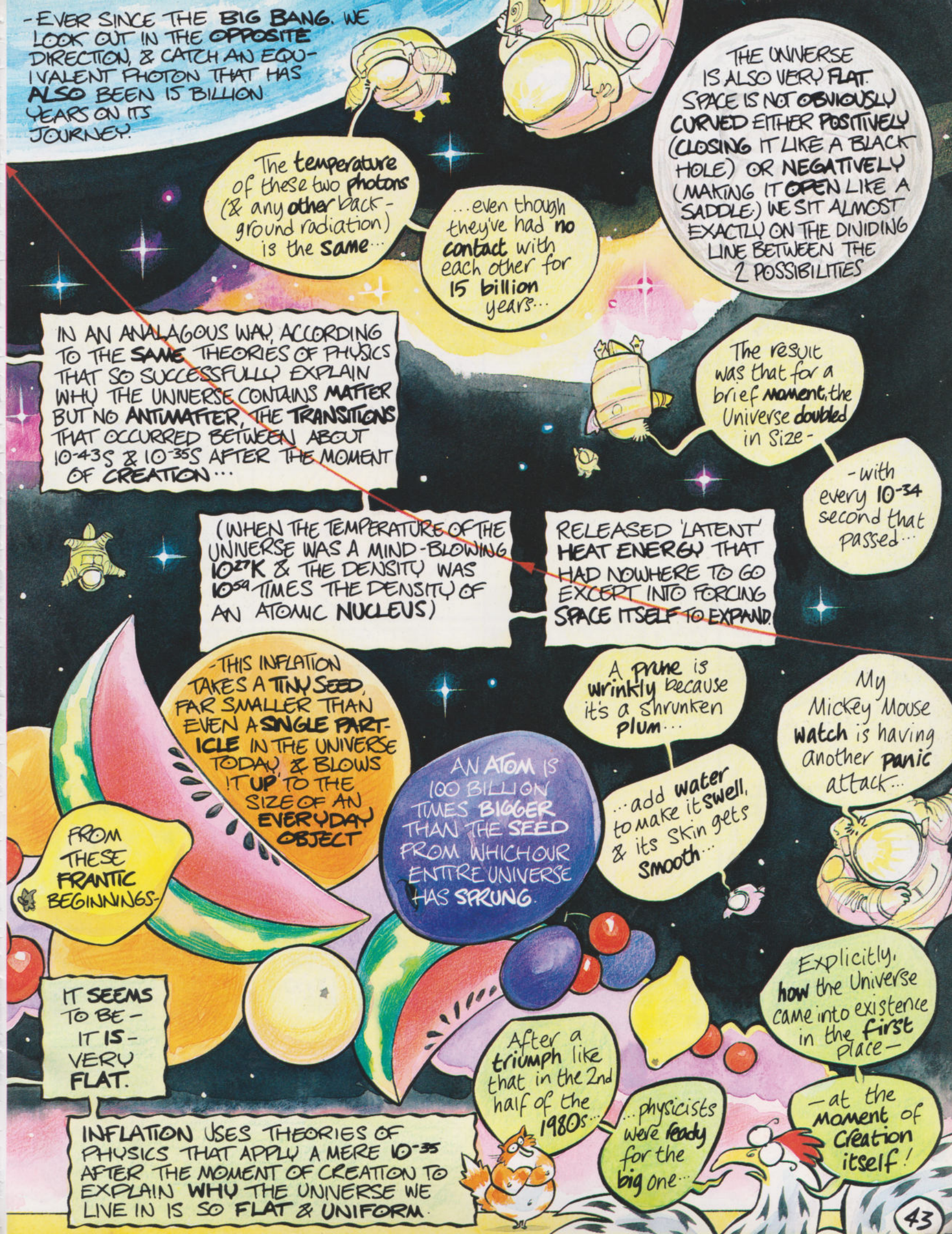
IN THE SAME WAY, COSMIC INFLATION STRETCHED & SMOOTHED OUT ANY WRINKLES IN SPACETIME.

THINK OF A TINY CHILD'S BALLOON; OBVIOUSLY, ITS SKIN IS CURVED - NOW INFLATE THAT BALLOON UNTIL IT IS MANY TIMES BIGGER THAN THE EARTH

YOU CAN WALK ABOUT ON ITS SURFACE - & NEVER NOTICE ANY CURVATURE

NO MATTER HOW CURVED SPACE WAS TO START WITH, AFTER STRETCHING IT BY A FACTOR OF 10^{50}, IT'S VERY FLAT INDEED...

OK- but just keep your claws in!


-EVER SINCE THE BIG BANG. WE LOOK OUT IN THE OPPOSITE DIRECTION, & CATCH AN EQUIVALENT PHOTON THAT HAS ALSO BEEN 15 BILLION YEARS ON ITS JOURNEY.
The temperature of these two photons (& any other background radiation) is the same...
...even though they've had no contact with each other for 15 billion years...
THE UNIVERSE IS ALSO VERY FLAT. SPACE IS NOT OBVIOUSLY CURVED EITHER POSITIVELY (CLOSING IT LIKE A BLACK HOLE) OR NEGATIVELY (MAKING IT OPEN LIKE A SADDLE.) WE SIT ALMOST EXACTLY ON THE DIVIDING LINE BETWEEN THE 2 POSSIBILITIES
IN AN ANALAGOUS WAY, ACCORDING TO THE SAME THEORIES OF PHYSICS THAT SO SUCCESSFULLY EXPLAIN WHY THE UNIVERSE CONTAINS MATTER BUT NO ANTIMATTER, THE TRANSITIONS THAT OCCURRED BETWEEN ABOUT 10^{-43}S & 10^{-35}S AFTER THE MOMENT OF CREATION...
The result was that for a brief moment, the Universe doubled in size-
-with every 10^{-34} second that passed...
(WHEN THE TEMPERATURE OF THE UNIVERSE WAS A MIND-BLOWING 10^{27}K & THE DENSITY WAS 10^{54} TIMES THE DENSITY OF AN ATOMIC NUCLEUS)
RELEASED 'LATENT' HEAT ENERGY THAT HAD NOWHERE TO GO EXCEPT INTO FORCING SPACE ITSELF TO EXPAND.
-THIS INFLATION TAKES A TINY SEED, FAR SMALLER THAN EVEN A SINGLE PARTICLE IN THE UNIVERSE TODAY, & BLOWS IT UP TO THE SIZE OF AN EVERYDAY OBJECT
A prune is wrinkly because it's a shrunken plum...
My Mickey Mouse watch is having another panic attack...
...add water to make it swell, & its skin gets smooth...
AN ATOM IS 100 BILLION TIMES BIGGER THAN THE SEED FROM WHICH OUR ENTIRE UNIVERSE HAS SPRUNG.
FROM THESE FRANTIC BEGINNINGS-
IT SEEMS TO BE - IT IS - VERY FLAT.
After a triumph like that in the 2nd half of the 1980s...
Explicitly, how the Universe came into existence in the first place-
...physicists were ready for the big one...
-at the moment of Creation itself!
INFLATION USES THEORIES OF PHYSICS THAT APPLY A MERE 10^{-35} AFTER THE MOMENT OF CREATION TO EXPLAIN WHY THE UNIVERSE WE LIVE IN IS SO FLAT & UNIFORM.

HOW DID TIME **BEGIN**? STEPHEN **HAWKING** THINKS HE KNOWS THE **ANSWER**-

IT **DIDN'T**, ACCORDING TO **HIS** VIEW OF THE UNIVERSE, WHICH HAS **NO EDGES**, EITHER OF **SPACE** OR **TIME**...

HAWKING GETS **RID** OF THE PUZZLE OF HOW THE UNIVERSE **BEGAN** BY SAYING THAT THERE WAS **NO** BEGINNING.

THIS IS POSSIBLE IF THE UNIVERSE IS **CLOSED**, IN THE **RELATIVISTIC** MEANING OF THE TERM (BUT ONLY JUST CLOSED BECAUSE INFLATON SAYS IT IS NEARLY **FLAT**)

IN RELATIVISTIC LANGUAGE, THAT WOULD MEAN IT WAS **BORN** IN A **SINGULARITY** AT THE MOMENT WHEN TIME BEGAN, 15 BILLION YEARS AGO...

The great **COSMIC EGG!**

THAT IT WILL **EXPAND OUT** TO SOME DEFINITE SIZE; & THAT IT WILL THEN **COLLAPSE BACK** INTO A SINGULARITY ONCE AGAIN, EXACTLY AS A BLACK HOLE COLLAPSES BACK INTO A SINGULARITY.

BANG

CRUNCH

BUT THERE'S ANOTHER WAY OF DESCRIBING ALL THIS. **SPACETIME** MAY BE LIKE THE SURFACE OF THE **EARTH** - WITH 2 EXTRA DIMENSIONS. (4 IN ALL.)

THE SURFACE OF THE EARTH HAS A **FINITE** AREA, BUT IT HAS NO **EDGES** - NO BOUNDARIES.

TIME COULD **ALSO** BE FINITE - BUT HAVE NO EDGES - NO SINGULARITIES.

IMAGINE DISTANCE FROM THE **NORTH POLE** AS REPRESENTING THE **AGE** OF THE UNIVERSE - (TIME SINCE THE BIG BANG)

- & THE LENGTH OF A LINE OF **LATITUDE**, A CIRCLE ROUND THE NORTH POLE, REPRESENTING THE **SIZE** OF THE UNIVERSE.

STARTING OUT FROM THE POLE, AS **TIME PASSES** THE 'UNIVERSE' GETS BIGGER **ALL** THE WAY TO THE **EQUATOR**, THEN SHRINKS **DOWN** ALL THE WAY TO THE SOUTH POLE.

BUT THERE IS **NO** SINGULARITY IN TIME AT **EITHER** OF THE POLES - JUST AS THERE IS NO '**EDGE**' TO THE EARTH AT EITHER OF THE POLES.

THERE IS **NO** TIME '**BEFORE**' THE BIG BANG, ANY MORE THAN THERE IS A DIRECTION '**NORTH**' AT THE NORTH POLE...

BUT JUST AS THE EARTH DOESN'T '**END**' AT THE POLE, SO TIME DOESN'T '**BEGIN**' IN THE BIG BANG...

AT THE **NORTH** POLE, ALL DIRECTIONS ARE **SOUTH**. IN THE BIG BANG, **ALL** TIME DIRECTIONS ARE THE **FUTURE**...

SOUTH

SOUTH

SOUTH

SOUTH

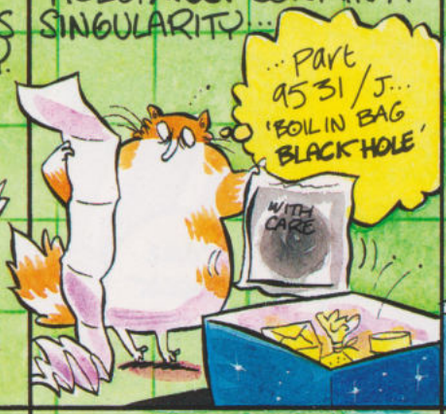
SOUTH

It's **true**! There's **no edge**!

MUSH!

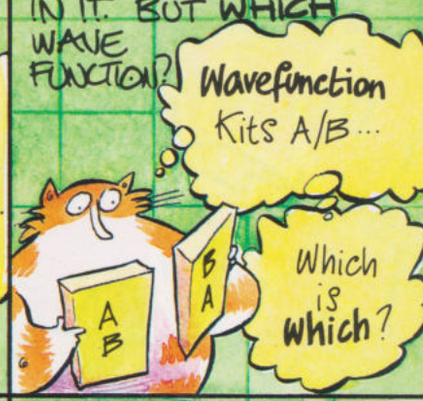
THE TRICK **WORKS** BECAUSE QUANTUM UNCERTAINTY **SMEARS OUT** THE **SINGULARITY** THAT APPEARS IN THE EQUATIONS OF GENERAL RELATIVITY.

RELATIVITY **ALONE** SAYS THE EXPANDING UNIVERSE, OR A COLLAPSING BLACK HOLE, **MUST** CONTAIN A SINGULARITY...

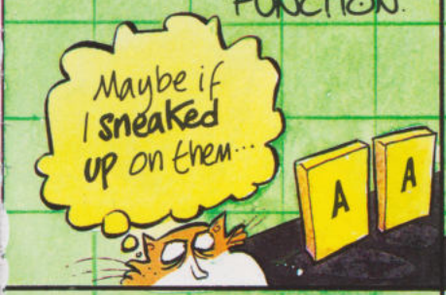


RELATIVITY **PLUS** QUANTUM THEORY (QUANTUM GRAVITY) NEED **NOT**. BUT HOW DO YOU APPLY QUANTUM THEORY TO THE **WHOLE UNIVERSE**?

THERE **OUGHT** TO BE A '**WAVE FUNCTION**' THAT DESCRIBES THE UNIVERSE & EVERYTHING IN IT. BUT **WHICH** WAVE FUNCTION?

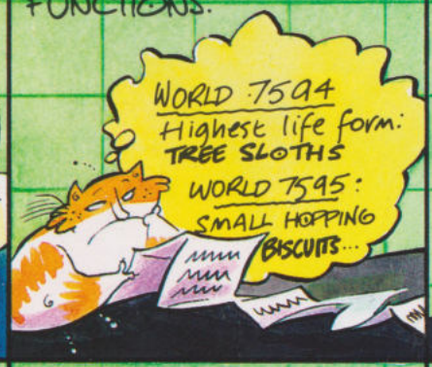


LIKE THE **CAT** IN A **BOX**, THE UNIVERSE OUGHT TO EXIST IN A **SUPERPOSITION** OF **STATES** UNTIL SOMEBODY **OUTSIDE** THE UNIVERSE **LOOKS** AT IT & 'COLLAPSES THE WAVEFUNCTION.'



BUT THERE **IS** NOBODY OUTSIDE! THE ONLY WAY TO DESCRIBE THE UNIVERSE IN **QUANTUM** TERMS IS USING THE **MANY WORLDS THEORY** -

-WHICH SAYS THAT **ALL POSSIBLE** WAVE FUNCTIONS **ALWAYS EXIST**. NOBODY CAN CALCULATE IN **DETAIL** EVEN **ONE** OF THOSE WAVEFUNCTIONS.

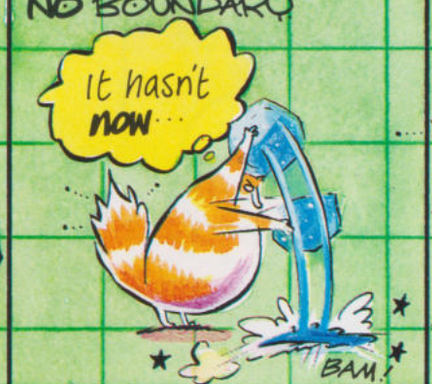


BUT IT **IS** POSSIBLE TO CALCULATE IN A GENERAL WAY HOW THE FAMILY OF WAVEFUNCTIONS **RELATES** TO THE **CONDITIONS** THAT APPLY AT THE BEGINNING & END OF THE UNIVERSE -(OR **UNIVERSES**...)

- THE SO-CALLED '**BOUNDARY CONDITIONS**'

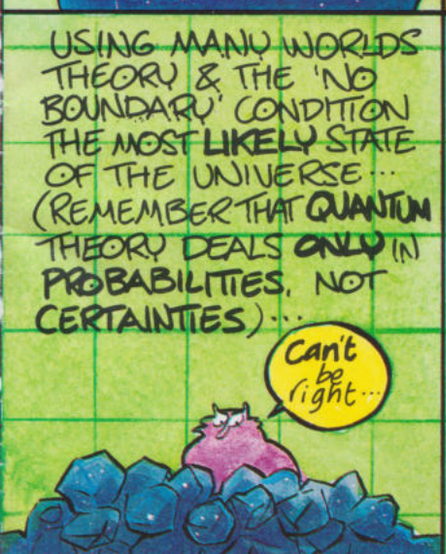
HAWKING QUIPS THAT HIS TRICK OF TREATING THE UNIVERSE AS A **4-DIMENSIONAL SPHERE**-

- IS EQUIVALENT TO SAYING THAT THE **BOUNDARY CONDITION** OF THE UNIVERSE IS THAT IT HAS **NO BOUNDARY**.



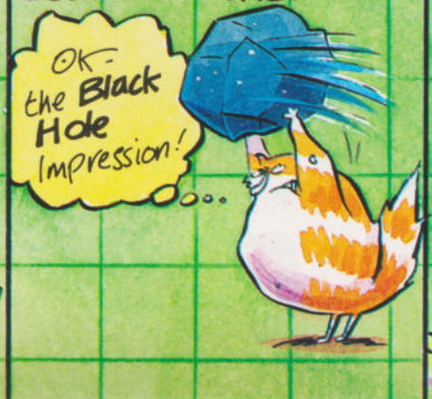
THAT SIMPLIFIES THE EQUATIONS JUST **LONG ENOUGH** FOR THEM TO BE **WORKABLE**...

USING MANY WORLDS THEORY & THE 'NO BOUNDARY' CONDITION THE MOST **LIKELY** STATE OF THE UNIVERSE... (REMEMBER THAT **QUANTUM** THEORY DEALS **ONLY** IN **PROBABILITIES**, NOT **CERTAINTIES**)...



AS SEEN BY ANYONE **INSIDE** IT, WILL BE THAT IT IS EXPANDING **UNIFORMLY** IN ALL DIRECTIONS AT **JUST** THE TIME **WE** ARE AROUND TO **SEE** IT.

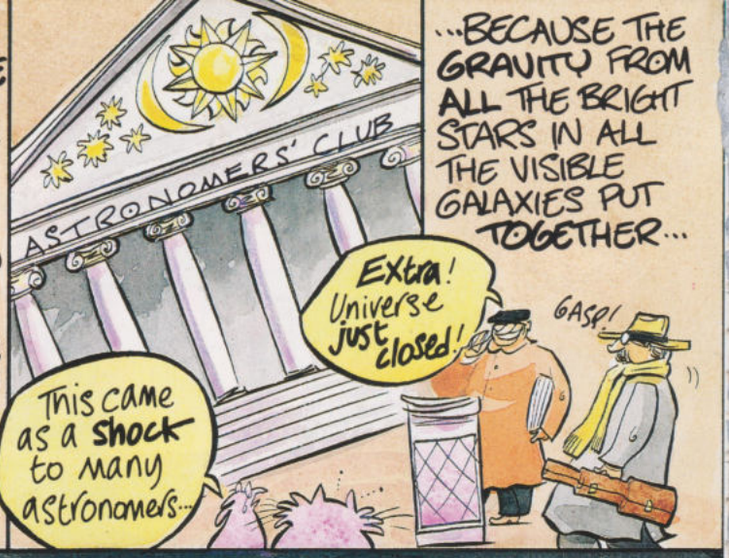
IF THE UNIVERSE HAS **NO** BOUNDARY - NO **BEGINNING** OR **END** - THEN IT IS **SELF-CONTAINED**.



BUT EVEN A SELF-CONTAINED UNIVERSE **MIGHT** HAVE BEEN CREATED BY QUANTUM PROCESSES, **WITH** OR **WITHOUT** THE HELP OF A **CREATOR**...

The DEATH of TIME 6

THEORIES THAT EXPLAIN WHAT HAPPENED **BEFORE** THE BIG BANG & HOW THE UNIVERSE CAME INTO BEING IN THE **FIRST** PLACE (INFLATION, QUANTUM COSMOLOGY - ACTUALLY PIONEERED BY JAYANT **NARLIKAR** & COLLEAGUES IN BOMBAY IN THE EARLY **1980s** - & THE **BUBBLE** THEORY) TOGETHER TELL US THAT THE UNIVERSE IS JUST **CLOSED**...

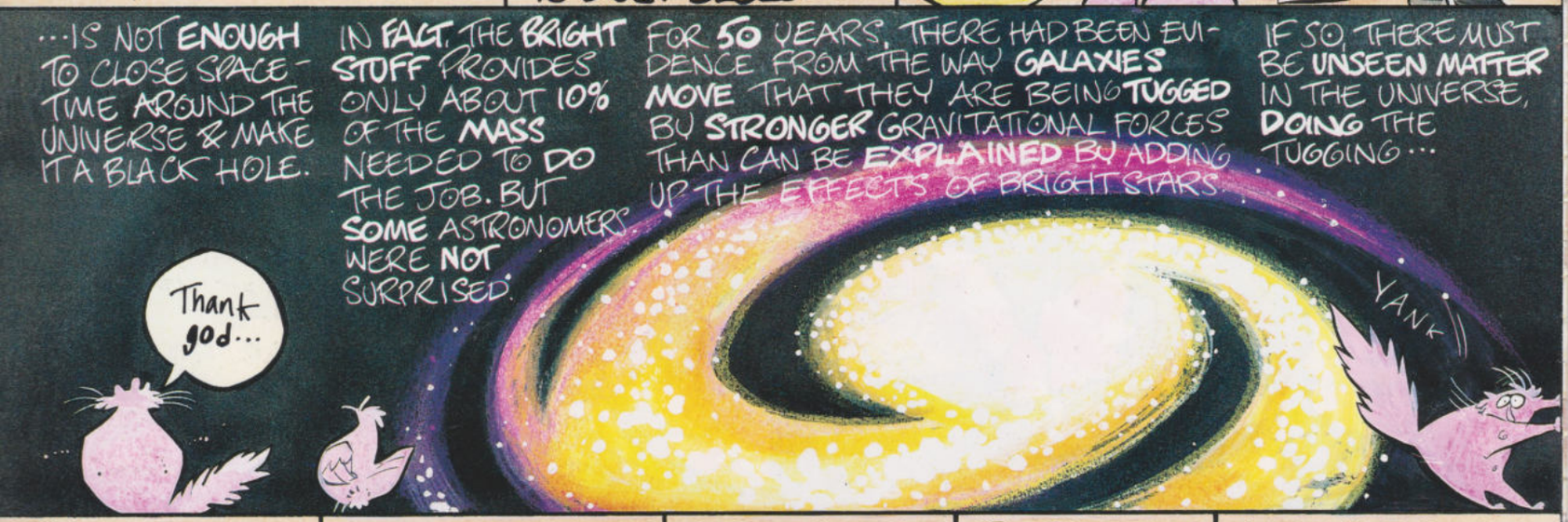

ASTRONOMERS' CLUB
...BECAUSE THE GRAVITY FROM ALL THE BRIGHT STARS IN ALL THE VISIBLE GALAXIES PUT TOGETHER...
Extra! Universe just closed!
GASP!
This came as a shock to many astronomers...

...IS NOT **ENOUGH** TO CLOSE SPACE-TIME AROUND THE UNIVERSE & MAKE IT A BLACK HOLE.

IN **FACT**, THE **BRIGHT STUFF** PROVIDES ONLY ABOUT **10%** OF THE **MASS** NEEDED TO **DO** THE JOB. BUT **SOME** ASTRONOMERS WERE **NOT** SURPRISED.

FOR **50** YEARS, THERE HAD BEEN EVIDENCE FROM THE WAY **GALAXIES MOVE** THAT THEY ARE BEING **TUGGED** BY **STRONGER** GRAVITATIONAL FORCES THAN CAN BE **EXPLAINED** BY ADDING UP THE EFFECTS OF BRIGHT STARS.

IF SO, THERE MUST BE **UNSEEN MATTER** IN THE UNIVERSE, **DOING** THE TUGGING...



THE OBSERVATIONS WERE **IGNORED** PARTLY OUT OF **PREJUDICE**. EVEN IN THE **1970s**...

MANY ASTRONOMERS SIMPLY DIDN'T WANT TO **BELIEVE** THAT THEY HAD SPENT THEIR **LIVES** STUDYING ONLY **10%** OF THE UNIVERSE...

& THAT THE **OTHER** 90% WOULD NEVER **SHOW UP** IN THE VIEW THROUGH THEIR **TELESCOPES**.

THIS PREJUDICE WAS **REINFORCED** BY THE STANDARD MODEL OF THE **BIG BANG**-

WHICH EXPLAINS SO **NEATLY** HOW MUCH **HYDROGEN** & **HELIUM** THERE IS IN THE UNIVERSE.

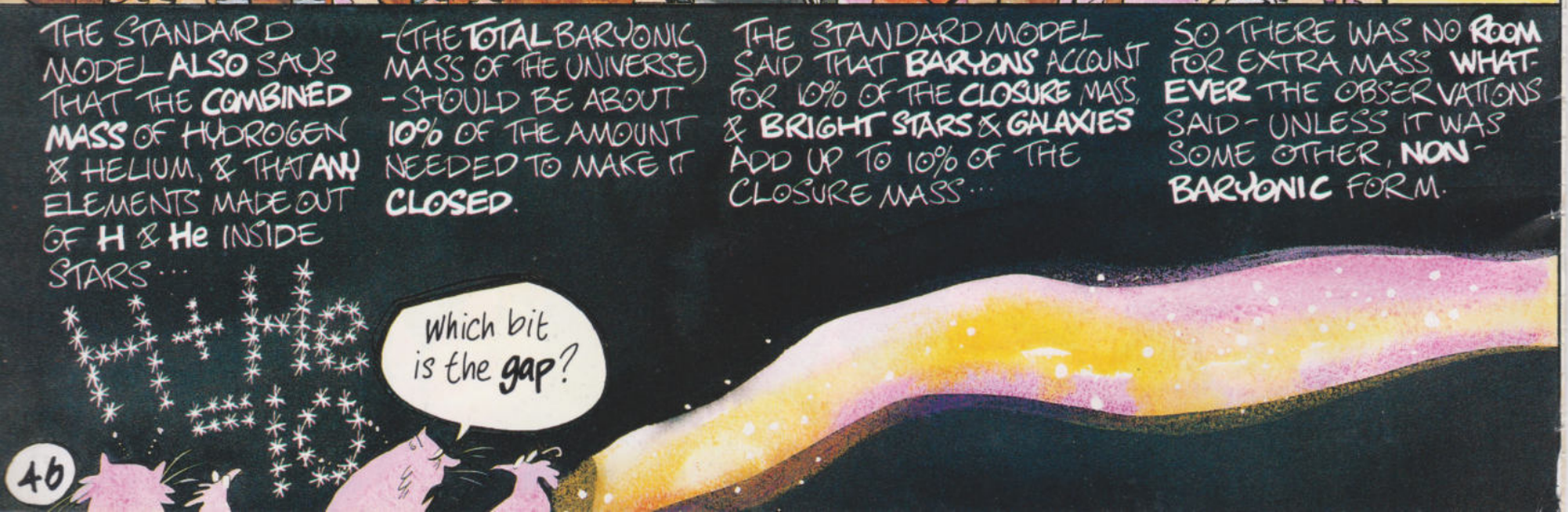
Z
Flying in the face of Nature!
Serves him right for writing 'Man-Master of the Universe'!
& what percentage shows up through that?
See? Even the new stuff says so!
It's an allegory of the H & He percentage in the Universe

THE STANDARD MODEL **ALSO** SAYS THAT THE **COMBINED MASS** OF HYDROGEN & HELIUM, & THAT **ANY** ELEMENTS MADE OUT OF **H** & **He** INSIDE STARS...

-(THE **TOTAL** BARYONIC MASS OF THE UNIVERSE) - SHOULD BE ABOUT **10%** OF THE AMOUNT NEEDED TO MAKE IT **CLOSED**.

THE STANDARD MODEL SAID THAT **BARYONS** ACCOUNT FOR 10% OF THE **CLOSURE** MASS, & **BRIGHT STARS** & **GALAXIES** ADD UP TO 10% OF THE CLOSURE MASS...

SO THERE WAS NO **ROOM** FOR EXTRA MASS **WHATEVER** THE OBSERVATIONS SAID - UNLESS IT WAS SOME OTHER, **NON-BARYONIC** FORM.



UNTIL THE 1980s, SUCH A SUGGESTION WAS VIRTUALLY SCIENTIFIC HERESY...

NOT JUST UNSEEN MATTER, BUT MATTER IN AN UNKNOWN FORM, MADE OF DIFFERENT KINDS OF PARTICLES FROM THE ATOMS THAT WE ARE USED TO.

BUT THE SAME NEW THEORIES OF PARTICLE PHYSICS THAT SO SUCCESSFULLY DESCRIBES THE VERY EARLY SPLIT SECONDS OF THE UNIVERSE...

...ALSO PREDICT THAT THERE MUST BE 'NEW' KINDS OF PARTICLE AROUND - DIFFERENT VERSIONS OF THOSE THEORIES PREDICT DIFFERENT PARTICLES.

So was Galileo, once...

Yes - but at least we can see what he was going on about...

GALAXY CLUSTER LIKE SWARM OF BEES... DIFFERENCE IN REDSHIFT...

Bzzzz

...TELLS HOW FAST THEY MOVE COMPARED WITH EACH OTHER. THIS IS BIGGER THAN THE ESCAPE VELOCITY FROM THE CLUSTER - UNLESS DARK MATTER IS IN THERE TOO.

NOBODY YET KNOWS WHETHER THE DARK MATTER IS IN THE FORM OF HIGGS BOSONS, MASSIVE NEUTRINOS, PHOTINOS, SQUARKS - OR SOMEBODY ELSE'S FAVOURITE.

Quentinos!

Rogerinos!

2 Distant Galaxies & a Betelguse Sunset, Madam...

MORE CAUTIOUS COSMOLOGISTS USUALLY CALL THE PARTICLES EITHER 'COSMIONS' OR 'COLD DARK MATTER' - USUALLY ABBREVIATED TO CDM.

mumble

DOUBTERS CORNER

BUT NOW, ONLY A SMALL MINORITY OF ASTRONOMERS DOUBT THAT IT IS THERE.

...flying in the face of Nature...

CDM EXPLAINS BEAUTIFULLY THE WAY GALAXIES ARE HELD TOGETHER IN CLUSTERS & HOW INDIVIDUAL GALAXIES ROTATE...

OK. If this Cold, Dark Meatball's a Galaxy...

IT ALSO EXPLAINS HOW GALAXIES FORMED IN THE FIRST PLACE IN THE EXPANDING UNIVERSE. AFTER HALF A CENTURY IN THE WILDERNESS, IT HAS COME IN FROM THE COLD. NOW, ASTRONOMERS CAN'T MANAGE WITHOUT IT.

EXPANDING SPACE WOULD HAVE PULLED THIN CLOUDS OF HYDROGEN & HELIUM GAS APART WHEN THE UNIVERSE WAS YOUNG BEFORE THEY COULD COLLAPSE GRAVITATIONALLY TO MAKE GALAXIES; BUT THE EXTRA GRAVITATIONAL ATTRACTION...

...OF 10 TIMES AS MUCH CDM PROVIDED GRAVITATIONAL 'POTHOLES' INTO WHICH THE BARYONIC MATTER FELL, LIKE WATER FORMING A DEEP PUDDLE IN A DAMAGED ROAD SURFACE.

RED SHIFT

BLUE SHIFT

We see spiral galaxies edge on...

Measurements show the disk is held in an invisible halo...

... of CDM...

Fancy! The M25 as a microcosm of the Cosmos!

THE EVIDENCE IS NOW SEEN AS COMPELLING THAT THE UNIVERSE IS CLOSED & WILL ONE DAY RECOLLAPSE. THERE IS AN IMPORTANT SCIENTIFIC LESSON (MORAL, EVEN-) HERE, AS THE 50-YEAR-OLD MEASUREMENTS HAVE BEEN VINDICATED...

ALWAYS BELIEVE YOUR OBSERVATIONS, NOT YOUR THEORIES! (NO MATTER HOW NEAR THEY MAY BE TO YOUR HEART) - IF THE TWO ARE IN CONFLICT!

COPY DOWN & MEMORISE

BUT THERE IS ALSO A CURIOUS SCIENTIFIC PUZZLE -

TRIVIAL PARTICLE PHYSICS

TIME FLOWS IN THE DIRECTION IN WHICH THE UNIVERSE EXPANDS...

SPORT. How many bosons in a tennis ball?

SO WHAT WILL HAPPEN TO THE FLOW OF TIME WHEN THE UNIVERSE REVERSES?

Z Z Z

not a lot in this gaff...

QUANTUM UNCERTAINTY SMEARS OUT THE MOMENT OF CREATION OVER A SPAN OF 10^{-43} SEC.

What's the matter now?

I'm bored!

THIS IS THE QUANTUM OF TIME - THE SMALLEST SLICE TIME CAN BE DIVIDED INTO -

- Just about your concentration span...

THE DIFFERENCE BETWEEN 10^{-43} & 0 IS TINY, BUT CRUCIAL. IT MEANS THE ORIGINAL DENSITY WAS ABSOLUTELY ENORMOUS, BUT NOT ACTUALLY INFINITE. SO THE EQUATIONS WORK!

JUST AS AN ELECTRON-POSITRON PAIR CAN POP INTO EXISTENCE & DISAPPEAR AGAIN THROUGH QUANTUM UNCERTAINTY,

Well - work on your tap routine...

Naaa

THE SEED OF A WHOLE UNIVERSE WITH AN 'AGE' OF 10^{-43} SEC. COULD POP INTO EXISTENCE OUT OF NOTHING AT ALL.

OK - have a go with this...

BORED? WHY NOT PLAY GOD?

SUCH A 'FLUCTUATION OF THE VACUUM' WOULD OCCUPY A TINY VOLUME SMALLER THAN A PROTON.

Not much about omnipotence...

BUT IT WOULD HAVE AN ENORMOUS GRAVITATIONAL FIELD, CORRESPONDING TO THE MASS-ENERGY OF THE WHOLE UNIVERSE.

Big on concept, though...

SO YOU MIGHT EXPECT IT TO COLLAPSE BACK INTO NOTHING AT ALL VERY QUICKLY INDEED...

Hm - what would God do?

BUT INFLATION PROVIDES A WAY OUT OF THIS TRAP.

Huh?

IN THE TINY FRACTION OF A SECOND THAT SUCH A SEED UNIVERSE EXISTS, INFLATION CAN SET TO WORK & BLOW IT UP INTO A FULL SIZE UNIVERSE.

Probably some sort of Zen exercise...

'FULL SIZE' MEANS SOMETHING ABOUT AS BIG AS A BASKETBALL

-CONTAINING AS MUCH ENERGY AS OUR UNIVERSE DOES TODAY, & EXPERIENCING A BIG BANG.

Divine Raiment, eh?

Wouldn't strike much awe...

FOR MANY THOUSANDS OF MILLIONS OF YEARS AFTERWARDS, IT WILL EXPAND OUTWARDS...

This is a scale model, isn't it?

WHILE STARS, PLANETS & PERHAPS PEOPLE FORM IN IT.

I dunno - you're God...

I s'pose basketball courts would be sorta churches...

BUT A UNIVERSE FORMED IN THIS WAY MUST ALWAYS BE CLOSED - IT MUST CONTAIN ENOUGH MASS-ENERGY

-FOR GRAVITY EVENTUALLY TO OVERPOWER EXPANSION & MAKE IT SHRINK BACK DOWN & DISAPPEAR.

Other sports would be rival religions...

So what's new?

YOU CAN GET SOMETHING FOR NOTHING BUT ONLY FOR A LIMITED TIME (BUT THE LIMIT MAY BE HUNDREDS OF BILLIONS OF YEARS)

PLINK

But why stop at one universe?

IF THIS COULD HAPPEN ONCE, 15 BILLION YEARS AGO, CAN'T THE SAME PROCESS BE GOING ON BETWEEN THE STARS TODAY?

Puts worrying about alien invasion into perspective...

-& WOULDN'T IT BE RATHER UNCOMFORTABLE FOR US IF A NEW EXPANDING UNIVERSE POPPED INTO EXISTENCE HALFWAY BETWEEN HERE & ALPHA CENTAURI?

Yes! I've seen the future - & it's all TV sport!

YES & NO. IT **COULD** HAPPEN- BUT IF IT **DID**, WE WOULDN'T EVEN **KNOW** ABOUT IT...

Promise?

REMEMBER THAT ANY **NEW** UNIVERSE MUST BE **CLOSED** IN THE RELATIVISTIC SENSE-

In other words - a **black hole**!

IT IS **POSSIBLE** TO IMAGINE CREATING THE SEED OF A NEW UNIVERSE **ARTIFICIALLY**...

Wait for it...

USING **HYDROGEN BOMBS** TO **COMPRESS** A REGION OF SPACE-TIME DOWN TO THE NECESSARY **SIZE**...

How about **that** for playing God?

BUT IF YOU **DID**, THE **BLACK HOLE** THAT YOU'D CREATED WOULD NOT START EXPLODING BACK IN YOUR **FACE**, SMASHING ITS WAY INTO **OUR** UNIVERSE...

Probably means they're **trying** it!

INSTEAD, IT EXPANDS IN A SET OF DIRECTIONS AT **RIGHT ANGLES** TO OUR FAMILIAR DIMENSIONS OF SPACE & TIME.

OUR **3** DIMENSIONS ARE AT RIGHT ANGLES TO EACH OTHER. **TIME** CAN BE THOUGHT OF AS A **4TH** DIMENSION AT **RIGHT ANGLES** TO ALL 3. THE NEW UNIVERSE HAS ITS **OWN** SET OF 4 DIMENSIONS, ALL OF THEM AT RIGHT ANGLES TO ALL THE DIMENSIONS OF **OUR** SPACETIME, & **SO** ON...

OUR UNIVERSE MIGHT HAVE BEEN DELIBERATELY CREATED IN THIS WAY, ALTHOUGH THERE IS **NO WAY** TO **FIND OUT**...

the **multi-dimensional** calculator...

SINCE EXACTLY THE **SAME THING** WILL HAPPEN TO **ANY** SEED UNIVERSES FORMED BY NATURAL FLUCTUATIONS.

Saved by cosmic geometry

I **think**...

YOU CAN PICTURE THIS BY THINKING OF **OUR** UNIVERSE AS THE **SKIN** OF AN **EXPANDING BALLOON** GETTING BIGGER AS THE BALLOON IS PUMPED UP.

Here!

COSMIC FOAM KIT

A '**NEW**' UNIVERSE CREATED WITHIN THAT SPACETIME (THE **SKIN** OF THE **BALLOON** IS LIKE A LITTLE **BUBBLE**, PINCHED OUT OF THE SKIN OF THE BALLOON, THAT EXPANDS IN IT'S **OWN RIGHT**...)

TWEAK

QUANTUM COSMOLOGY ALLOWS THE POSSIBILITY OF CREATING NOT JUST **ONE** UNIVERSE

BUT AN **INFINITE** NUMBER OF UNIVERSES OUT OF NOTHING AT ALL...

The **ecologically safe** way!

...INTERCONNECTED IN SOME **COMPLEX**, MULTI DIMENSIONAL WAY - BUBBLES LIKE **FOAM** ON A **RIVER**...

...or frogspawn

EITHER ON HAWKING'S PICTURE, OR ON THIS PICTURE, THERE IS NO '**BEGINNING**' OF TIME IN THE **COSMIC** SENSE

BUT TO HUMAN BEINGS, THE BIG BANG IS A PRETTY **DEFINITE BEGINNING**.

Pretty **definite** for us chickens...

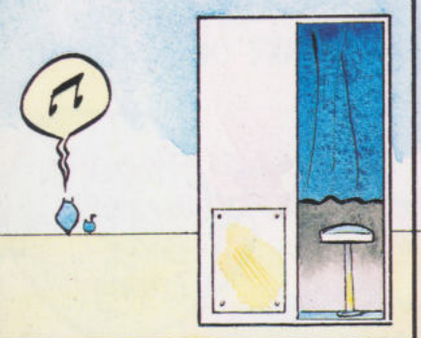
& FROM OUR HUMAN PERSPECTIVE, EVEN THOUGH THE **FROTH** ON THE **NEVER ENDING** RIVER OF TIME MAY EXTEND **INDEFINITELY**,

But **how** - & **when**?!

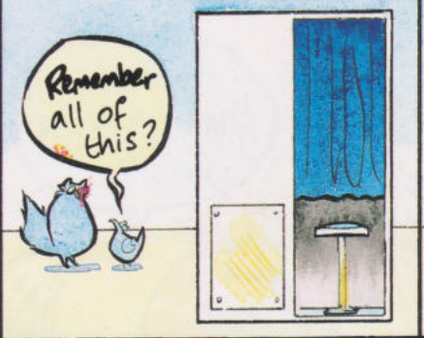
WHEN OUR **OWN** LITTLE BUBBLE COLLAPSES, THAT WILL BE **THE END**.

THRRRP

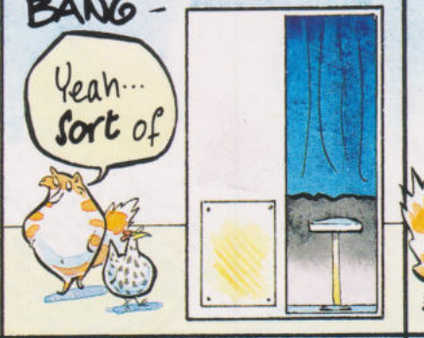
IN HAWKING'S UNIVERSE, THE ARROW OF TIME POINTS OUTWARD FROM THE 'NORTH POLE'



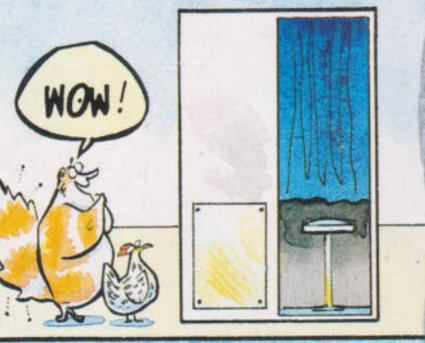
THE FUTURE IS THE DIRECTION IN WHICH SUCCESSIVE LINES OF LATITUDE GET BIGGER.



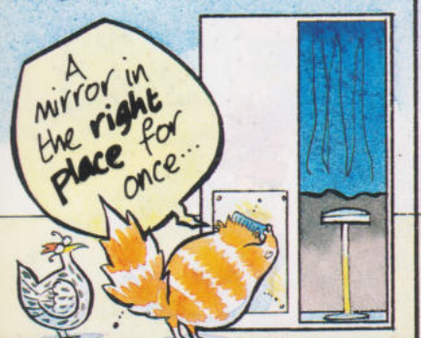
THIS REPRESENTS THE GROWTH OF ENTROPY AS THE UNIVERSE EXPANDS AWAY FROM THE NEAT SIMPLICITY OF THE BIG BANG -



& BECOMES MORE DISORDERED AS STARS & BLACK HOLES FORM, CRUMPLING UP LOCAL REGIONS OF SPACETIME...

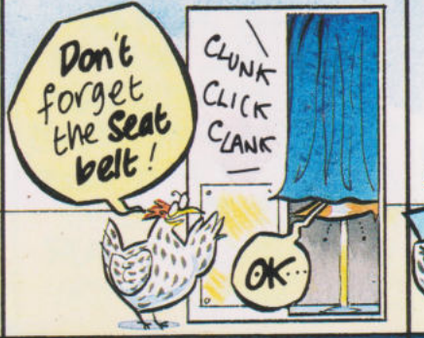


WITH THE OTHER SIDE OF THE 'EQUATOR' CORRESPONDING TO THE TIME WHEN THE UNIVERSE REACHES ITS MAXIMUM SIZE.

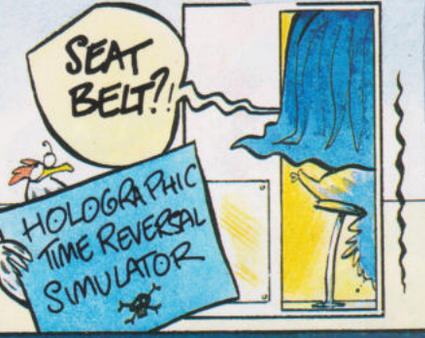


IF WE KEEP MOVING IN THE SAME DIRECTION, AWAY FROM THE NORTH POLE,

SUCCESSIVE LINES OF LATITUDE GET SMALLER ALL THE WAY DOWN TO THE SOUTH POLE ...



THERE, ALL THE MESS & CONFUSION IN THE UNIVERSE IS WIPED AWAY...

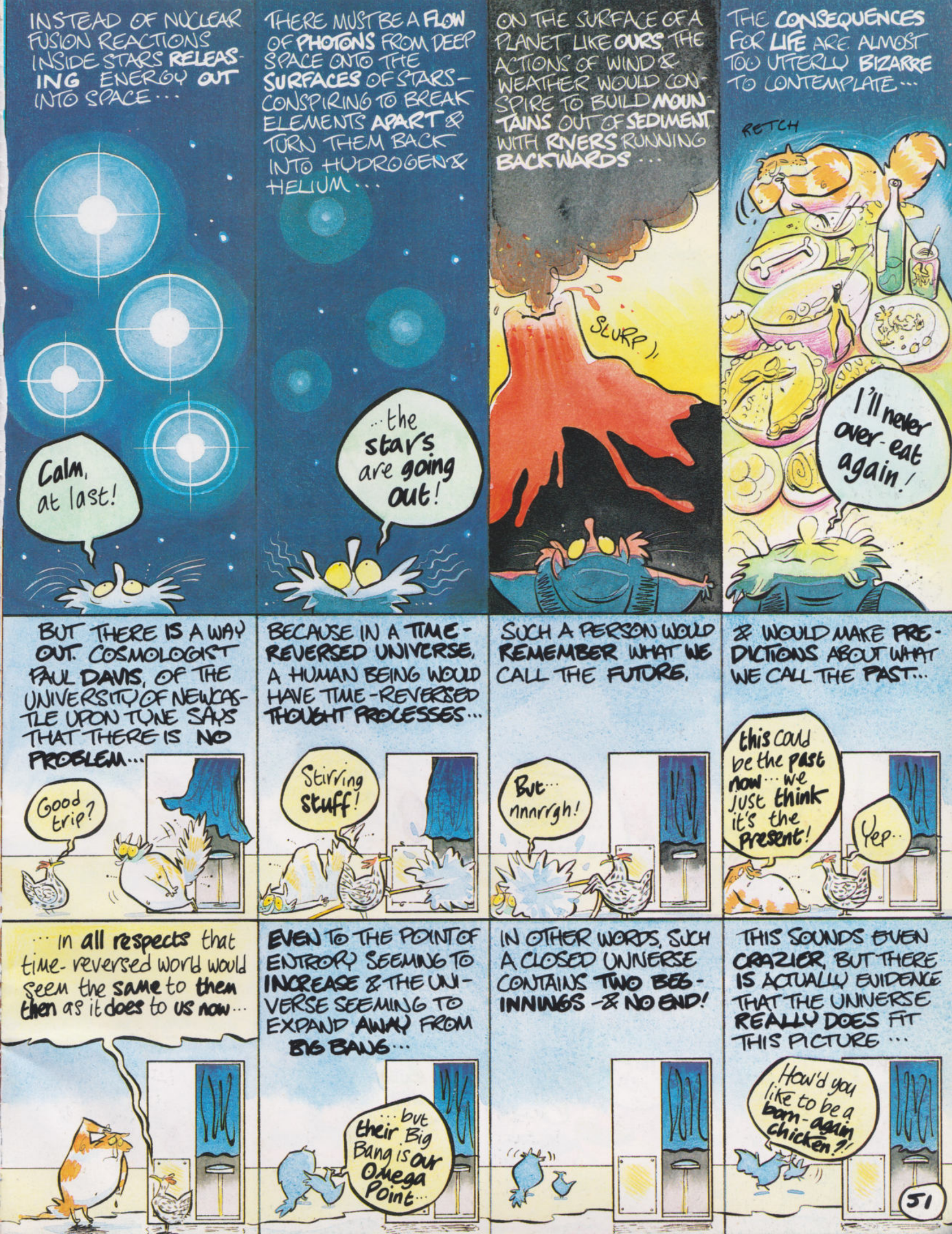


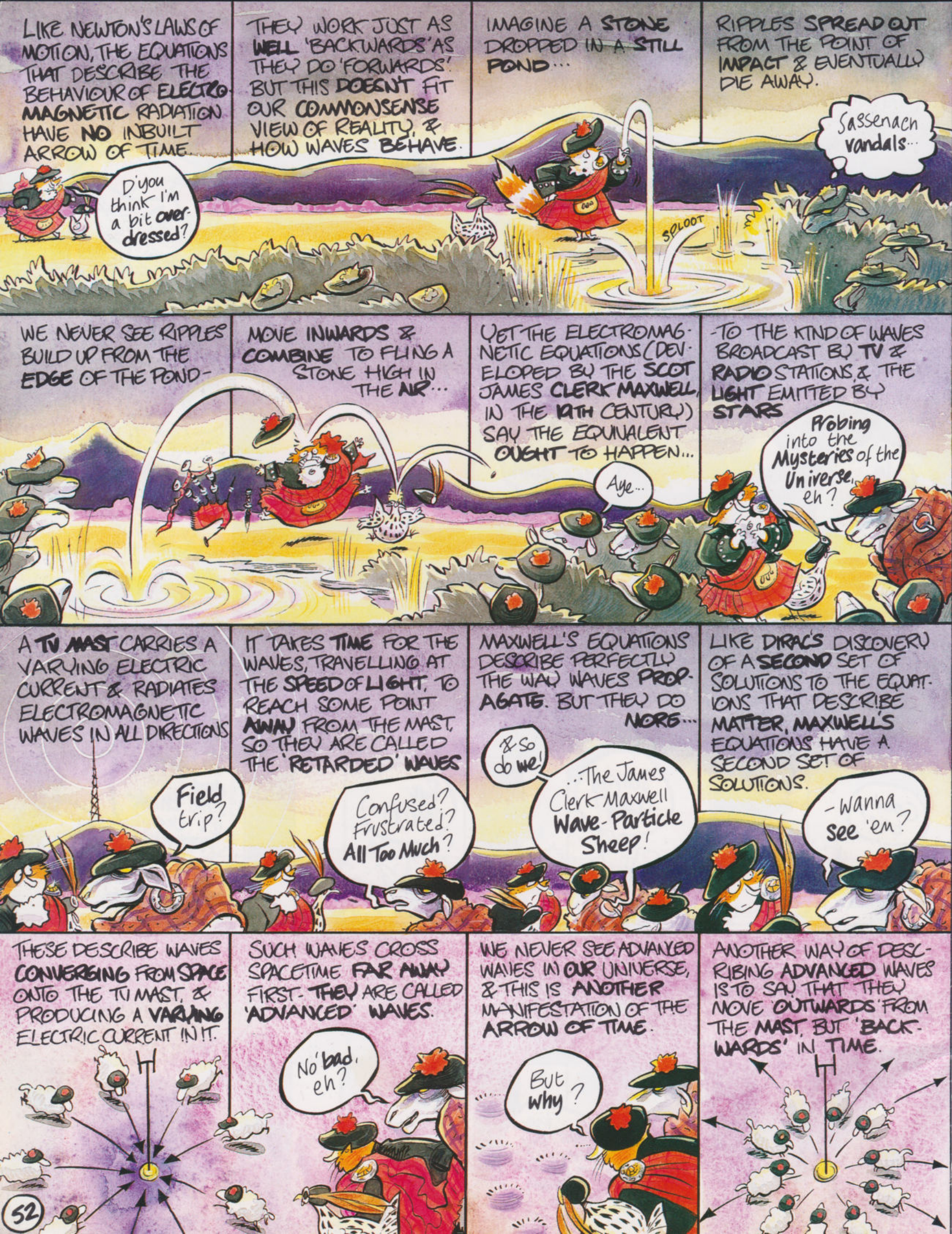
AS EVERYTHING IS SWALLOWED UP INTO A 'NEW', SMOOTH, SINGULARITY. THE MIRROR IMAGE OF THE BIG BANG...

THIS SINGULARITY AT THE END OF TIME IS SOMETIMES REFERRED TO AS THE BIG CRUNCH - OR MORE SOBERLY, AS THE OMEGA POINT -

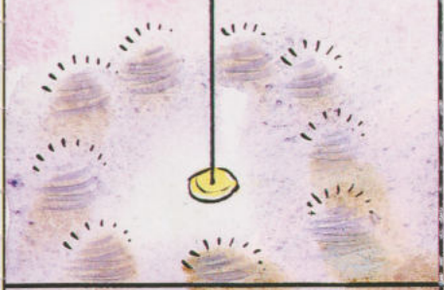
IT LOOKS AS IF THE UNIVERSE IS SHRINKING & ENTROPY IS DECREASING IN THE OTHER HALF OF SPACE-TIME...

IN OTHER WORDS, TIME RUNS BACKWARDS...


INSTEAD OF NUCLEAR FUSION REACTIONS INSIDE STARS RELEASING ENERGY OUT INTO SPACE...
Calm, at last!
THERE MUST BE A FLOW OF PHOTONS FROM DEEP SPACE ONTO THE SURFACES OF STARS - CONSPIRING TO BREAK ELEMENTS APART & TURN THEM BACK INTO HYDROGEN & HELIUM...
...the stars are going out!
ON THE SURFACE OF A PLANET LIKE OURS, THE ACTIONS OF WIND & WEATHER WOULD CONSPIRE TO BUILD MOUNTAINS OUT OF SEDIMENT, WITH RIVERS RUNNING BACKWARDS...
SLURP!
THE CONSEQUENCES FOR LIFE ARE ALMOST TOO UTTERLY BIZARRE TO CONTEMPLATE...
RETCH
I'll never over-eat again!
BUT THERE IS A WAY OUT. COSMOLOGIST PAUL DAVIS, OF THE UNIVERSITY OF NEWCASTLE UPON TYNE SAYS THAT THERE IS NO PROBLEM...
Good trip?
BECAUSE IN A TIME-REVERSED UNIVERSE, A HUMAN BEING WOULD HAVE TIME-REVERSED THOUGHT PROCESSES...
Stirring stuff!
SUCH A PERSON WOULD REMEMBER WHAT WE CALL THE FUTURE.
But... nnnrrgh!
& WOULD MAKE PREDICTIONS ABOUT WHAT WE CALL THE PAST...
this could be the past now... we just think it's the present!
Yep...
...in all respects that time-reversed world would seem the same to them then as it does to us now...
EVEN TO THE POINT OF ENTROPY SEEMING TO INCREASE & THE UNIVERSE SEEMING TO EXPAND AWAY FROM BIG BANG...
...but their Big Bang is our Omega Point...
IN OTHER WORDS, SUCH A CLOSED UNIVERSE CONTAINS TWO BEGINNINGS - & NO END!
THIS SOUNDS EVEN CRAZIER, BUT THERE IS ACTUALLY EVIDENCE THAT THE UNIVERSE REALLY DOES FIT THIS PICTURE...
How'd you like to be a born-again chicken?!
51

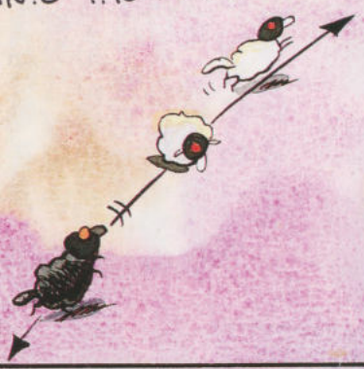

LIKE NEWTON'S LAWS OF MOTION, THE EQUATIONS THAT DESCRIBE THE BEHAVIOUR OF ELECTRO-MAGNETIC RADIATION HAVE NO INBUILT ARROW OF TIME.
THEY WORK JUST AS WELL 'BACKWARDS' AS THEY DO 'FORWARDS'. BUT THIS DOESN'T FIT OUR COMMONSENSE VIEW OF REALITY, & HOW WAVES BEHAVE.
IMAGINE A STONE DROPPED IN A STILL POND...
RIPPLES SPREAD OUT FROM THE POINT OF IMPACT & EVENTUALLY DIE AWAY.
D'you think I'm a bit over-dressed?
SPLOOT
Sassenach vandals...
WE NEVER SEE RIPPLES BUILD UP FROM THE EDGE OF THE POND-
MOVE INWARDS & COMBINE TO FLING A STONE HIGH IN THE AIR...
YET THE ELECTROMAGNETIC EQUATIONS (DEVELOPED BY THE SCOT JAMES CLERK MAXWELL IN THE 19TH CENTURY) SAY THE EQUIVALENT OUGHT TO HAPPEN...
-TO THE KIND OF WAVES BROADCAST BY TV & RADIO STATIONS, & THE LIGHT EMITTED BY STARS
Aye...
Probing into the Mysteries of the Universe, eh?
A TV MAST CARRIES A VARYING ELECTRIC CURRENT & RADIATES ELECTROMAGNETIC WAVES IN ALL DIRECTIONS
IT TAKES TIME FOR THE WAVES, TRAVELLING AT THE SPEED OF LIGHT, TO REACH SOME POINT AWAY FROM THE MAST, SO THEY ARE CALLED THE 'RETARDED' WAVES
MAXWELL'S EQUATIONS DESCRIBE PERFECTLY THE WAY WAVES PROPAGATE. BUT THEY DO MORE...
LIKE DIRAC'S DISCOVERY OF A SECOND SET OF SOLUTIONS TO THE EQUATIONS THAT DESCRIBE MATTER, MAXWELL'S EQUATIONS HAVE A SECOND SET OF SOLUTIONS.
Field trip?
Confused? Frustrated? All Too Much?
& so do we!
...The James Clerk Maxwell Wave-Particle Sheep!
-Wanna see 'em?
THESE DESCRIBE WAVES CONVERGING FROM SPACE ONTO THE TV MAST, & PRODUCING A VARYING ELECTRIC CURRENT IN IT.
SUCH WAVES CROSS SPACETIME FAR AWAY FIRST- THEY ARE CALLED 'ADVANCED' WAVES.
No 'bad, eh?
WE NEVER SEE ADVANCED WAVES IN OUR UNIVERSE, & THIS IS ANOTHER MANIFESTATION OF THE ARROW OF TIME.
But why?
ANOTHER WAY OF DESCRIBING ADVANCED WAVES IS TO SAY THAT THEY MOVE OUTWARDS FROM THE MAST, BUT 'BACKWARDS' IN TIME.

IN THE 1940s US PHYSICISTS JOHN WHEELER & RICHARD FEYNMAN FOUND A WAY TO EXPLAIN WHERE THE ADVANCED WAVES HAD GONE.

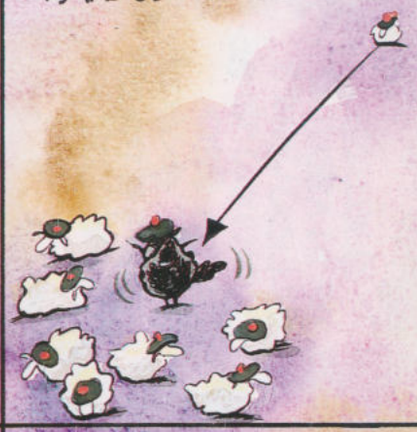


THE WAVE PRODUCED BY A SINGLE ELECTRON FEEDS BACK ON ITSELF LIKE THIS:

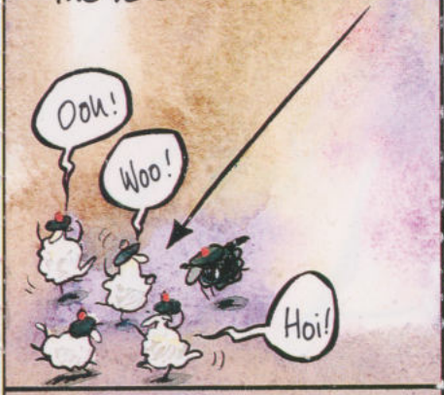
THE RETARDED WAVE MOVES OFF INTO THE FUTURE, & THE ADVANCED WAVE MOVES BACK INTO THE PAST...



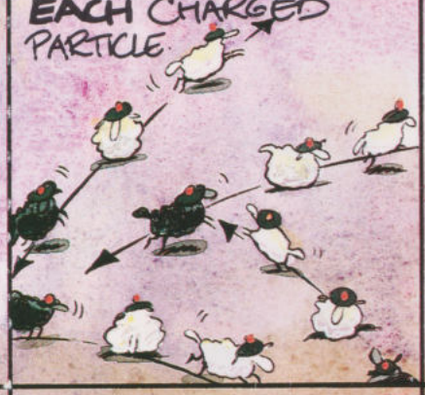
THE ADVANCED WAVE ARRIVES AT OTHER CHARGED PARTICLES...



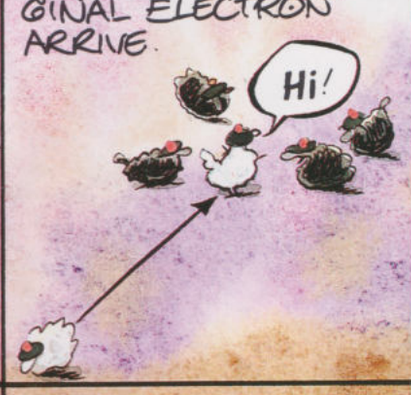
...& JIGGLES THEM ABOUT BEFORE THE FIRST ELECTRON MOVES.



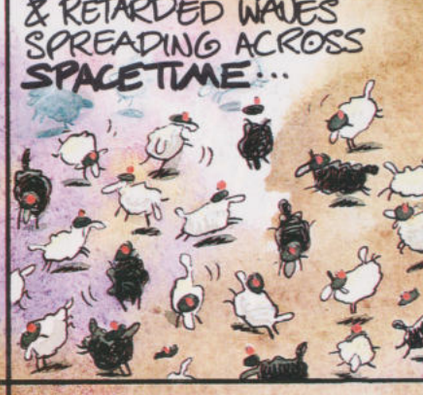
THAT JIGGLING MAKES A NEW SET OF ADVANCED & RETARDED WAVES SPREADING OUT FROM EACH CHARGED PARTICLE.



THE SAME THING HAPPENS IN THE FUTURE, WHEN THE RETARDED WAVES FROM THE ORIGINAL ELECTRON ARRIVE.



THE RESULT, FROM MOVING ONE ELECTRON BRIEFLY, IS A SEA OF OVERLAPPING ADVANCED & RETARDED WAVES SPREADING ACROSS SPACETIME...



BUT BECAUSE ALL THE WAVES ORIGINATE FROM THE FIRST ELECTRON, THEY INTERFERE WITH EACH OTHER IN A RELATIVELY SIMPLE WAY.

WHEN WHEELER & FEYNMAN CARRIED THE CALCULATIONS THROUGH PROPERLY, THEY FOUND THAT ALL THE WAVES CANCEL OUT...

EXCEPT FOR A SINGLE SET OF RETARDED WAVES MOVING INTO THE FUTURE FROM THE ORIGINAL ELECTRON—

BUT THE CANCELLING OF ADVANCED WAVES ONLY WORKS IF THE UNIVERSE BEHAVES LIKE ONE OF THE CLOSED BOXES BELOVED BY THERMODYNAMICISTS...

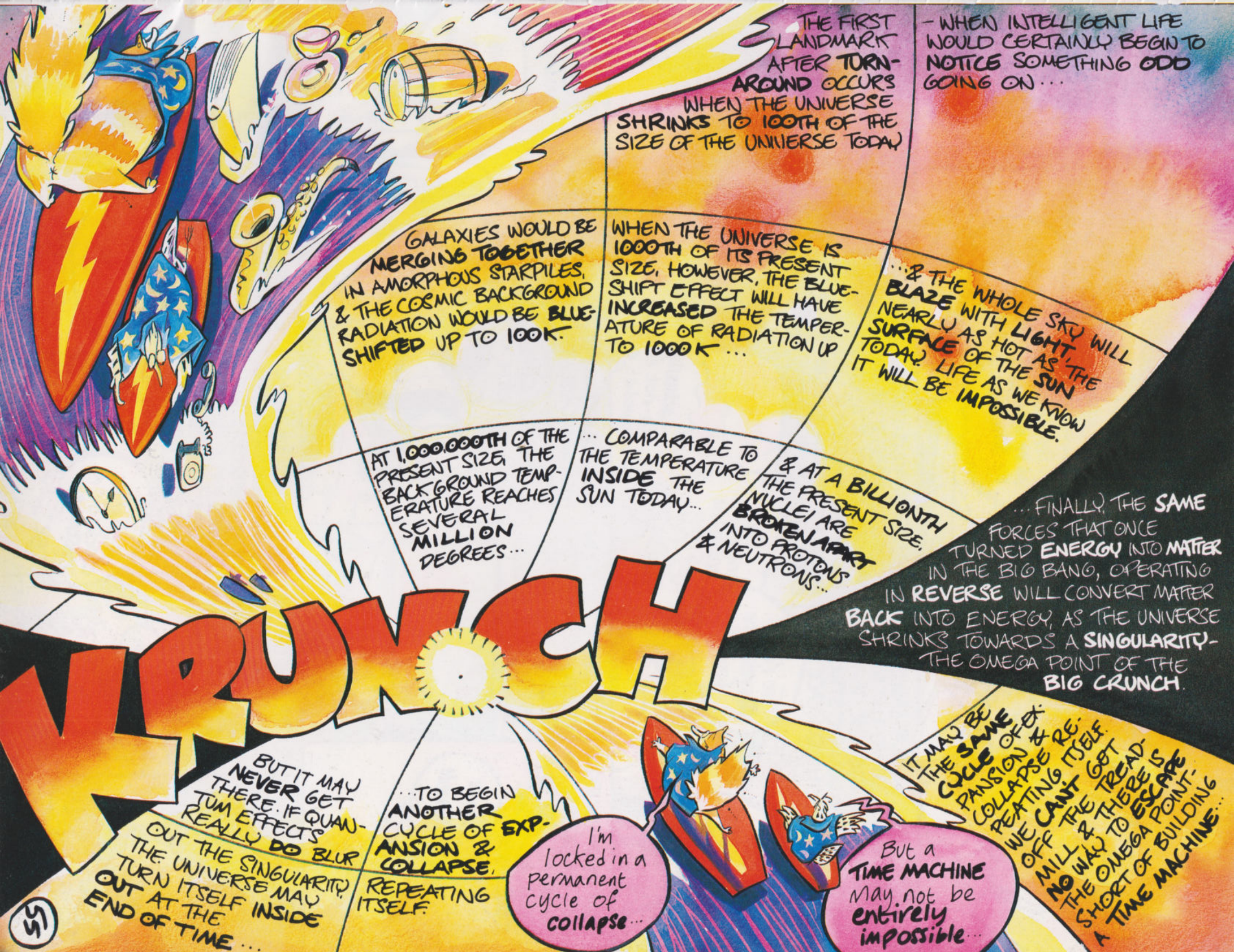
IF RADIATION CAN ESCAPE INTO THE FUTURE & NEVER MEET ANOTHER CHARGED PARTICLE, THERE ARE NO WAVES COMING BACK FROM THE FUTURE TO DO THE CANCELLING OUT...

THE UNIVERSE ITSELF MUST BE A CLOSED BOX, WITH A 'PERFECT ABSORBER' IN THE FUTURE...

THE FUTURE MUST BE A CONTRACTING PHASE OF THE UNIVERSE, WITH TIME REVERSAL, IN ORDER TO EXPLAIN THE WAY A TV SIGNAL GETS FROM THE TRANSMITTER TO YOUR HOME TODAY.

TIME WILL COME TO AN END, AS FAR AS OUR PRESENT PERSPECTIVE IS CONCERNED.

43
EVEN IF THE UNIVERSE IS CLOSED & MUST ONE DAY RECOLLAPSE 'ONE DAY' MAY LIE VERY FAR IN THE FUTURE...
INFLATION REQUIRES THAT SPACETIME IS VERY NEARLY FLAT...
...& THE FLATTER IT IS, THE LONGER IT WILL TAKE FOR THE EXPANSION TO HALT & REVERSE.
STARTING OUT PAROCHIALLY, THERE WILL BE AMPLE TIME FOR OUR SUN...
SWELLING UP IN ABOUT 5 BILLION YEARS FROM NOW TO BECOME A RED GIANT ENGULFING THE PLANET MERCURY...
TO REACH OLD AGE -
IT WILL COOL & FADE, & THE EARTH WILL FREEZE.
...& THEN SHRINKING BACK AS ITS NUCLEAR FUEL IS EXHAUSTED, SETTLING DOWN TO A QUIET OLD AGE AS A BALL OF STAR STUFF ABOUT AS BIG AS THE EARTH - A WHITE DWARF.
MANY STARS WILL SUFFER THE SAME FATE; MUCH BIGGER STARS THAN OUR SUN, HOWEVER, END THEIR LIVES VIOLENTLY...
...GIVING UP THEIR LAST BURSTS OF ENERGY IN EXPLOSIONS WHICH SCATTER HEAVY ELEMENTS THROUGH SPACE & LEAVE BEHIND TINY REMNANTS, STARS MADE ENTIRELY OF NEUTRONS,
-IN WHICH AS MUCH MASS AS OUR SUN CONTAINS IS SQUEEZED INTO A BALL NO BIGGER THAN A LARGE MOUNTAIN ON EARTH.
RED GIANT
SUN
WHITE DWARF
(50,000,000 KM)
(700,000 KM)
(6000 KM)
NEUTRON STAR (10 KM)
BLACK HOLE
3KM
SOME WILL EVEN BECOME BLACK HOLES. EVERY STAR MUST END UP AS A WHITE DWARF, A NEUTRON STAR OR A BLACK HOLE. BUT WHAT HAPPENS THEN?
LEAVING ASIDE THE PHILOSOPHICAL QUESTIONS ABOUT THE MEANING OF TIME IN THE COLLAPSING HALF OF THE UNIVERSE, JUST LOOK AT THINGS FROM OUR PERSPECTIVE OF TIME -
-AS IF WE REALLY COULD SEE INTO THE FUTURE.
EVEN AFTER THE UNIVERSE 'TURNS AROUND' & STARTS TO COLLAPSE, LIFE COULD STILL GO ON PRETTY MUCH AS IT DOES NOW, WITH STARS BEING BORN, LIVING THEIR LIVES & DYING.


THE FIRST LANDMARK AFTER TURN-AROUND OCCURS WHEN THE UNIVERSE SHRINKS TO 100TH OF THE SIZE OF THE UNIVERSE TODAY
- WHEN INTELLIGENT LIFE WOULD CERTAINLY BEGIN TO NOTICE SOMETHING ODD GOING ON...
GALAXIES WOULD BE MERGING TOGETHER IN AMORPHOUS STARPILES, & THE COSMIC BACKGROUND RADIATION WOULD BE BLUE-SHIFTED UP TO 100K.
WHEN THE UNIVERSE IS 1000TH OF ITS PRESENT SIZE, HOWEVER, THE BLUE-SHIFT EFFECT WILL HAVE INCREASED THE TEMPERATURE OF RADIATION UP TO 1000K...
...& THE WHOLE SKY WILL BLAZE WITH LIGHT, NEARLY AS HOT AS THE SURFACE OF THE SUN TODAY. LIFE AS WE KNOW IT WILL BE IMPOSSIBLE.
AT 1,000,000TH OF THE PRESENT SIZE, THE BACKGROUND TEMPERATURE REACHES SEVERAL MILLION DEGREES...
...COMPARABLE TO THE TEMPERATURE INSIDE THE SUN TODAY...
& AT A BILLIONTH THE PRESENT SIZE, NUCLEI ARE BROKEN APART INTO PROTONS & NEUTRONS...
...FINALLY, THE SAME FORCES THAT ONCE TURNED ENERGY INTO MATTER IN THE BIG BANG, OPERATING IN REVERSE WILL CONVERT MATTER BACK INTO ENERGY, AS THE UNIVERSE SHRINKS TOWARDS A SINGULARITY- THE OMEGA POINT OF THE BIG CRUNCH.
CRUNCH
BUT IT MAY NEVER GET THERE. IF QUANTUM EFFECTS REALLY DO BLUR OUT THE SINGULARITY, THE UNIVERSE MAY TURN ITSELF INSIDE OUT AT THE END OF TIME...
...TO BEGIN ANOTHER CYCLE OF EXPANSION & COLLAPSE, REPEATING ITSELF.
I'm locked in a permanent cycle of collapse...
But a TIME MACHINE may not be entirely impossible...
IT MAY BE THE SAME CYCLE OF EXPANSION & COLLAPSE RE-PEATING ITSELF. WE CAN'T GET OFF THE TREAD-MILL & THERE IS NO WAY TO ESCAPE THE OMEGA POINT- SHORT OF BUILDING A TIME MACHINE...
55

TIME TRAVEL 7

TIME IS MORE ELASTIC THAN EVERYDAY EXPERIENCE LEADS YOU TO BELIEVE...

Oh-I dunno...

... Departure will be delayed by 30 minutes...

Well, I made that 30 minutes at least 3 hours...

JUST AS COMMONSENSE GAINED FROM LIFE ON THE SURFACE OF A MODEST-SIZED PLANET IS NO GUIDE TO WHAT HAPPENS ON THE VERY SMALL SCALE, WHERE QUANTUM RULES APPLY,

SO IT'S NO GUIDE TO WHAT HAPPENS WHEN YOU TRAVEL AT HIGH SPEEDS...

True. My ears have gone funny...

...OR LIVE IN A STRONG GRAVITATIONAL FIELD, WHERE RELATIVISTIC RULES APPLY.

You can unfasten your gravitational field now...

IN BOTH CASES, TIME LITERALLY RUNS SLOWER THAN IF YOU SIT STILL ON THE SURFACE OF THE EARTH

Too right! Where's the food?!

THIS IS RELATED TO THE OBSERVED FACT THAT THE SPEED OF LIGHT IS ALWAYS THE SAME, WHEREVER YOU MEASURE IT FROM, & HOWEVER FAST YOU'RE MOVING...

I've never crowed at 25000 feet...

...actually, I've not even crowed at 0.75 feet...

IF AN ASTRONAUT MOVING AT 3/4 OF THE SPEED OF LIGHT (0.75c) FIRES A PROJECTILE ON AHEAD OF HIM OR HER AT HALF THE SPEED OF LIGHT (0.5c)

Fore!

SKRAWK!

YOU MIGHT EXPECT THE PROJECTILE TO MOVE AT 1.25c TO A STAY-AT-HOME OBSERVER...

Sounds reasonable

IT DOESN'T. EINSTEIN DISCOVERED THAT THE CORRECT WAY TO ADD VELOCITIES IS:

$$V = \frac{V_1 + V_2}{1 + \frac{V_1 V_2}{c^2}}$$

THIS BOILS DOWN TO THE 'COMMONSENSE' $V = V_1 + V_2$ IF THE VELOCITIES ARE SMALL COMPARED WITH c.

c

Not hungry?

BUT FOR ANY CASE OF 2 VELOCITIES SMALLER THAN c ADDED TOGETHER

Well! What have we here?

THE TOTAL IS LESS THAN c.

Sure you're not talking about airline food?

FOR EXAMPLE, IF EACH VELOCITY IS 0.75c, THE TOTAL IS 0.96c

Get the hand luggage...

BUT IF ONE OF THE VELOCITIES IS c, THE TOTAL IS ALWAYS c - THE SPEED OF LIGHT IS A UNIVERSAL CONSTANT.

sigh

A SIMILAR EQUATION DESCRIBES HOW THE TIME BETWEEN THE TICKS OF A MOVING CLOCK INCREASES AS THE SPEED INCREASES...

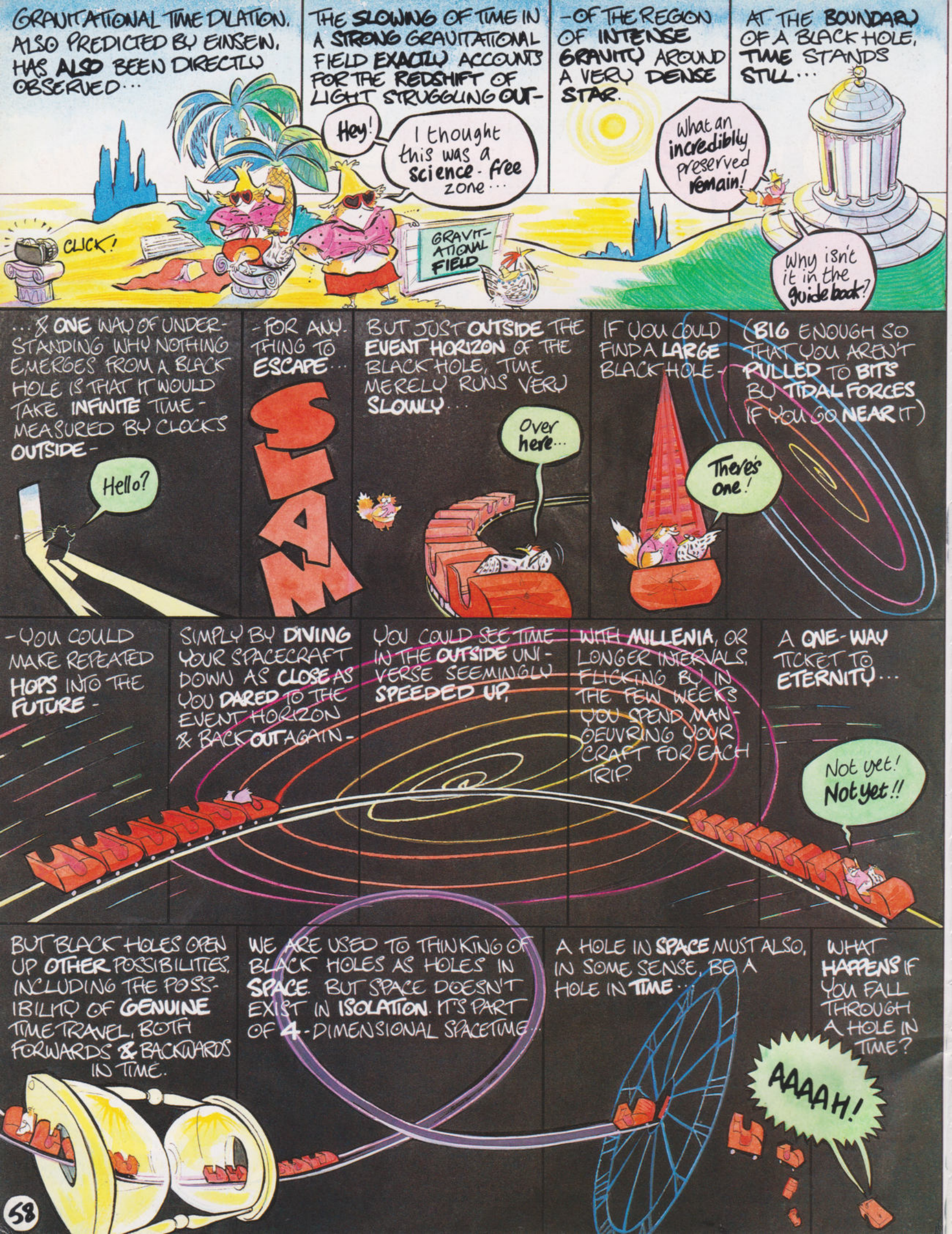
$$T = \frac{t}{\sqrt{1 - v^2/c^2}}$$

Is that a clock or a castanet?!

THE PASSAGE OF TIME SLOWS AS THINGS MOVE FASTER, DWINDLING AWAY TO A HALT AS THE VELOCITY APPROACHES c

That's the best description of a landing I've ever heard!

ONE WAY TO TRAVEL INTO THE FUTURE IS TO GO ON A LONG JOURNEY AT HIGH SPEED
No danger here, then...
WHEN YOU RETURN, MANY MORE YEARS WILL HAVE PASSED ON EARTH THAN YOU HAVE EXPERIENCED ON YOUR JOURNEY.
Yeah! I like it!
THIS IS TIME TRAVEL OF A SORT, BUT ONLY ONE WAY TIME TRAVEL, INTO THE FUTURE.
Here's another!
IT'S AS IF, INSTEAD OF FLOATING DOWN THE RIVER OF TIME, YOU ROARED DOWNSTREAM IN A FAST MOTORBOAT...
PLUNK!
MOVING INTO THE FUTURE FASTER THAN 24 HOURS A DAY - & REACHING FUTURE LANDMARKS DOWNSTREAM IN A MATTER OF HOURS...
BUT YOU NEED TO MOVE REALLY FAST TO DO ANY GOOD - EVEN AT HALF THE SPEED OF LIGHT...
THIS MAY NOT BE PRACTICABLE TIME TRAVEL FOR PEOPLE BUT IT HAS BEEN SEEN TO OPERATE FOR FAST MOVING PARTICLES...
My ninth life already?!
YOU ONLY GAIN A FACTOR OF ⅓ FOR EVERY YEAR OF YOUR JOURNEY - JUST ONE YEAR & 4 MONTHS PASSED ON EARTH...
Life in the fast lane...
You should worry - I get to be the mother of eggs!
...THEM TO REACH THE GROUND. THE EXPLANATION IS THAT FOR THE MOVING PARTICLES LESS TIME HAS ELAPSED & THEY HAVE NOT HAD TIME TO DECAY BEFORE THEY ARRIVE AT OUR DETECTORS.
UNSTABLE PARTICLES THAT ARE CREATED WHEN ENERGETIC COSMIC RAYS STRIKE THE TOP OF THE EARTH'S ATMOSPHERE ARE DETECTED AT GROUND LEVEL, EVEN THOUGH THEY 'SHOULD' HAVE DECAYED INTO OTHER PARTICLES IN THE BRIEF TIME THAT IT TAKES...
Look - how about a nice, restful fossil-hunting trip next time?
& ALL THESE RELATIVISTIC EFFECTS ARE ALLOWED FOR IN THE DESIGN OF PARTICLE ACCELERATORS LIKE THE ONES AT CERN.
IF TIME DILATION DID NOT OPERATE EXACTLY AS EINSTEIN CALCULATED,
& he did it all with pencil & paper!
ELASTIC TIME IS NOT SOME WILD & UNTESTED NOTION - TIME DILATION ASSOCIATED WITH MOTION IS PROVEN, BY EXPERIMENTS, TO BE A FACT OF UNIVERSAL LIFE...
What?! After the self-catering fiasco at Porton Down?
...THOSE ACCELERATORS SIMPLY WOULD NOT WORK
I've always fancied a package holiday to CERN...


GRAVITATIONAL TIME DILATION, ALSO PREDICTED BY EINSEIN, HAS ALSO BEEN DIRECTLY OBSERVED...
THE SLOWING OF TIME IN A STRONG GRAVITATIONAL FIELD EXACTLY ACCOUNTS FOR THE REDSHIFT OF LIGHT STRUGGLING OUT-
-OF THE REGION OF INTENSE GRAVITY AROUND A VERY DENSE STAR.
AT THE BOUNDARY OF A BLACK HOLE, TIME STANDS STILL...
CLICK!
Hey!
I thought this was a science-free zone...
GRAVIT-ATIONAL FIELD
What an incredibly preserved remain!
Why isn't it in the guide book?
...& ONE WAY OF UNDER-STANDING WHY NOTHING EMERGES FROM A BLACK HOLE IS THAT IT WOULD TAKE INFINITE TIME - MEASURED BY CLOCKS OUTSIDE -
Hello?
-FOR ANY-THING TO ESCAPE...
SIAM
BUT JUST OUTSIDE THE EVENT HORIZON OF THE BLACK HOLE, TIME MERELY RUNS VERY SLOWLY...
Over here...
IF YOU COULD FIND A LARGE BLACK HOLE -
There's one!
(BIG ENOUGH SO THAT YOU AREN'T PULLED TO BITS BY TIDAL FORCES IF YOU GO NEAR IT)
-YOU COULD MAKE REPEATED HOPS INTO THE FUTURE -
SIMPLY BY DIVING YOUR SPACECRAFT DOWN AS CLOSE AS YOU DARED TO THE EVENT HORIZON & BACK OUT AGAIN -
YOU COULD SEE TIME IN THE OUTSIDE UNI-VERSE SEEMINGLY SPEEDED UP,
WITH MILLENIA, OR LONGER INTERVALS, FLICKING BY IN THE FEW WEEKS YOU SPEND MAN-OEUVRING YOUR CRAFT FOR EACH TRIP.
A ONE-WAY TICKET TO ETERNITY...
Not yet! Not yet!!
BUT BLACK HOLES OPEN UP OTHER POSSIBILITIES, INCLUDING THE POSS-IBILITY OF GENUINE TIME TRAVEL, BOTH FORWARDS & BACKWARDS IN TIME.
WE ARE USED TO THINKING OF BLACK HOLES AS HOLES IN SPACE. BUT SPACE DOESN'T EXIST IN ISOLATION. IT'S PART OF 4-DIMENSIONAL SPACETIME...
A HOLE IN SPACE MUST ALSO, IN SOME SENSE, BE A HOLE IN TIME...
WHAT HAPPENS IF YOU FALL THROUGH A HOLE IN TIME?
AAAAH!
58

THE BLACK HOLES WE HAVE DISCUSSED SO FAR ARE NON-ROTATING. THEY JUST SIT THERE IN SPACE...

SWALLOWING UP ANYTHING THAT COMES TOO CLOSE & CRUSHING IT INTO THE CENTRAL SINGULARITY, BUT THIS ISN'T REALLY VERY REALISTIC.

JUST ABOUT EVERYTHING IN THE UNIVERSE ROTATES: THE EARTH, SUN, OTHER PLANETS & OTHER STARS

& LIKE A SKATER WHO SPINS FASTER WHEN SHE PULLS HER ARMS IN, ANYTHING THAT SHRINKS WILL SPIN FASTER...

No? Thank god...

EEEEEEEEEEEEK!

THIS, FOR THOSE WHO REALLY WANT TO KNOW, IS THE LAW OF CONSERVATION OF ANGULAR MOMENTUM: BIG THINGS HAVE MORE MOMENTUM, & THIS TURNS INTO FASTER SPIN WHEN THEY SHRINK.

A ROTATING BLACK HOLE IS DIFFERENT FROM A NON-ROTATING BLACK HOLE IN ONE PARTICULARLY IMPORTANT WAY-

INSTEAD OF HAVING A SINGLE EVENT HORIZON, & A POINT OF SINGULARITY AT ITS CENTRE,

A ROTATING BLACK HOLE HAS TWO EVENT HORIZONS, WITH SPACETIME AROUND THE SUN REGULARLY DISTORTED IN SUCH A WAY-

THAT IT OPENS A GATEWAY TO ANOTHER REGION OF SPACETIME - IN EFFECT, THROUGH THE SINGULARITY & OUT THE OTHER SIDE...

Big deal...

Both my event horizons are about to radically distort...

STARTING FROM EVERYDAY SPACE, A TRAVELLER COULD, IN PRINCIPLE, PASS THROUGH BOTH EVENT HORIZONS, EMERGING INTO ANOTHER REGION OF SPACE.

BUT NOT JUST ANOTHER REGION OF SPACE...

SUCH A JOURNEY COULD TAKE YOU INTO THE FUTURE OR THE PAST, OR EVEN INTO ANOTHER UNIVERSE ALTOGETHER (PERHAPS THERE'S A WAY TO ESCAPE THE BIG CRUNCH!)

MOST PHYSICISTS, & OTHER PEOPLE, DRAW BACK IN HORROR AT THE PROSPECT

...another region of spacetime!

& I'm here to tell them they're right!

1066 2001 3590 1962 1966

GENUINE TIME TRAVEL RAISES ALL KINDS OF PARADOXES, ALONG THE LINES OF A TRAVELLER WHO GOES BACK IN TIME & KILLS HER OWN GRANNY BEFORE HER MOTHER IS BORN...

Where did the time traveller come from?

BUT, PARADOXES OR NO, THERE IS NOTHING IN THE LAWS OF PHYSICS THAT FORBIDS TIME TRAVEL...

& OUR COMMON SENSE HAS BEEN PROVED FAULTY AT LEAST TWICE.

FOR TRAVEL SICKNESS

IT MAY, THOUGH, BE VERY DIFFICULT TO BUILD A PRACTICAL, WORKING TIME MACHINE.

What the hell - think big!

LET'S LOOK AT HOW IT MIGHT BE DONE - GIVEN UNLIMITED RESOURCES...

In 1974, Frank Tipler of Tulane University, New Orleans, caused a flurry in scientific dovecotes...

RUBBISH HOLIDAY READING

BEST OF PHYSICAL REVIEW

...BY PUBLISHING A PAPER IN THE HIGHLY RESPECTABLE PHYSICAL REVIEW IN WHICH HE PROVED THAT TIME TRAVEL IS POSSIBLE.

Or at least, not forbidden by the laws of physics...

UNDEMANDING NOVEL

HEAVY STUFF

FIRST, HE SHOWED THAT EQUATIONS ALLOW IN THEORY FOR THE EXISTENCE OF JOURNEYS THROUGH SPACETIME WHICH RETURN TO THEIR STARTING POINT...

You unnatural fowl! I'm off to do holiday stuff!

...IN BOTH SPACE & TIME- 'CLOSED TIMELIKE LOOPS' IN WHICH PART OF THE JOURNEY MUST BE BACKWARDS IN TIME...

You're ridiculous!

THEN, HE PROVED THAT THE CONDITIONS REQUIRED FOR CLOSED TIMELIKE LOOPS COULD ARISE NATURALLY IN THE UNIVERSE.

Manifest through a time warp, did they?

FINALLY, HE SHOWED HOW IT IS POSSIBLE, IN PRINCIPLE, TO CONSTRUCT AN ARTIFICIAL TIME MACHINE...

Look...

IT ALL DEPENDS ON THE WAY MASSIVE ROTATING OBJECTS DISTORT SPACETIME...

DRAGGING THE DIMENSIONS OF SPACETIME AROUND WITH THE ROTATION, & MAKING THE DIMENSIONS 'TIP OVER' IN A 4-DIMENSIONAL SENSE...

THREE AXES OF SPACE & ONE OF TIME ARE ALL, REMEMBER, PERPENDICULAR TO EACH OTHER.

FORWARD

RIGHT

UP

A traveller who keeps moving 'forward'

IN THE STRONG GRAVITATIONAL FIELD REGION NEAR A VERY DENSE ROTATING OBJECT, HOWEVER,

F

U

R

...as they pass into a strong field...

THE DRAG EFFECT TIPS THESE 4 PERPENDICULAR DIRECTIONS SO THAT THE DIRECTION THAT USED TO REPRESENT TIME BECOMES A SPACE DIRECTION—

F

U

R

actually ends up moving 'right'...

WHILE ONE OF THE SPACE DIMENSIONS BECOMES A TIME DIMENSION.

'Time' here being more of an axis in the mind...

U

R

F

IN PRACTICAL TERMS, THE ROLES OF SPACE & TIME HAVE BEEN REVERSED.

Not very romantic though, is it?

In a cerebral sort of way...

A TRAVELLER MOVING THROUGH SPACE IN THIS DISTORTED REGION OF SPACETIME IS MOVING THROUGH TIME IN THE WORLD OUTSIDE—

C'mon... we'll have a 'Time Machine'!

—WHERE GRAVITY IS WEAK—SUCH A TRAVELLER COULD JOURNEY INTO THE DISTORTED REGION,

Cheers!

BACKWARDS IN TIME & BACK OUT INTO THE EVERYDAY WORLD WITHOUT EVER VIOLATING THE RULES OF RELATIVITY.

It's all true!

IN ORDER TO **DO** THE TRICK, THOUGH, YOU NEED A **LOT** OF **MATTER**, ABOUT **10** TIMES THE MASS OF THE **SUN**, ROTATING VERY FAST, **TWICE** EVERY **1000TH** OF A **SECOND** - THE DENSITY HAS TO BE SO GREAT THAT A **SINGULARITY** FORMS AT THE **CENTRE**.

IF THE 'TIME MACHINE' WERE **NOT** ROTATING - THAT WOULD MEAN IT WAS A **BLACK HOLE** SO THE TRAVELLER COULD **NEVER** GET BACK INTO THE OUTSIDE AFTER ALL...

Don't **stop**!

BUT VERY FAST ROTATION ALSO HAS THE EFFECT OF **FLINGING AWAY** THE EVENT HORIZON...

Lose your **inhibitions** & **event** horizons!

2 more!

-LEAVING A **'NAKED'** SINGULARITY BEHIND. -ONE YOU CAN TRAVEL **CLOSE TO** & STILL **ESCAPE FROM**...

SUCH AN OBJECT **COULD** OCCUR NATURALLY IF A **NEUTRON** STAR WERE TO **SPIN FAST** ENOUGH.

That one's doing it!

They're **all** doing it!

'ALL' THAT YOU **NEED** TO **MAKE** A TIME MACHINE IS A **CYLINDER** AS **DENSE** AS A NEUTRON STAR, ABOUT **10** KM **ACROSS** & **100** KM **LONG** -

10KM

100KM

SPINNING **TWICE** EVERY MILLI SECOND, SO THAT THE **RIM** OF THE CYLINDER IS MOVING AT **HALF** THE SPEED OF LIGHT.

WEAK FIELD

STRONG FIELD

WEAK FIELD

(ACTUALLY, THIS IS LIKE **10 NEUTRON STARS** JOINED END TO END - OR POLE TO POLE...)

MANUFACTURING SUCH AN OBJECT MIGHT PROVE INSURMOUNTABLY **DIFFICULT**. BUT NOT LONG AFTER TIPLER CAME UP WITH THE DESCRIPTION OF A WORKING TIME MACHINE,

TIME MACHINE HOLDINGS, INC. ™ ©

KEY RINGS!

BLACK HOLE COASTERS!

-SWALLOWS YOUR DRINK PROBLEM!

ASTRONOMERS IDENTIFIED A FEW RAPIDLY ROTATING NEUTRON STARS, KNOWN AS **PULSARS**, THAT **REALLY DO** SPIN ONCE EVERY ONE OR TWO MILLISECONDS.

GULP

Black Hole **Boxers**?!

NO **RESPECTABLE** SCIENTIST HAS DARED TO MAKE THE CONNECTION, BUT IT IS ASTONISHING THAT OBJECTS WHICH BEAR SUCH A **CLOSE RESEMBLANCE** TO THE RELATIVISTIC DESCRIPTION OF A WORKING TIME MACHINE **REALLY DO** EXIST IN OUR UNIVERSE.

IF WE COULD FIND ONE **NEARBY**, & ENCOURAGE IT TO SPIN JUST A LITTLE BIT **FASTER**,

MY **OTHER** STARS A PULSAR

WE WOULD BE ABLE TO **TEST** TIPLER'S IDEAS & FIND OUT WHETHER TIME TRAVEL IS **POSSIBLE**.

Read the **book**? Seen the **video**? Worn the **T-shirt**?

EVEN **THAT** IS A DAUNTING PROSPECT. THE **GOOD** NEWS IS THAT YOU ONLY HAVE TO DO THE TRICK FOR A **FLEETING** INSTANT.

- Sick of the **present**? **Dogged** by **past** mistakes?

SINCE AT THE MOMENT OF ITS **CREATION** THE TIME MACHINE IS TIED **FOREVER** TO ALL CLOSED TIMELIKE LINES INTO THE **FUTURE**.

TIME TRAVEL AGENCY

Try a Getaway **one-way** ticket!

YOU CAN NEVER GO BACK IN TIME **EARLIER** THAN THE MOMENT THAT THE TIME MACHINE **EXISTED**...

But even if it did only **exist** for a **moment**, it opens up the **entire future** for exploration!

WITH **UNLIMITED** ENGINEERING ABILITY, THOUGH, A SPACEFARING CIVILIZATION **COULD CONSTRUCT** AN EVEN **MORE** USEFUL KIND OF TIME MACHINE...

IN 1989, RESEARCHERS AT CALTECH (HEADED BY KIP **THORNE**) & MOSCOW STATE UNIVERSITY (HEADED BY IGOR **NOVIKOV**) JOINED FORCES TO AMAZE THEIR COLLEAGUES WITH A **NEW** VARIATION ON THE THEME...

They suggest using **WORMHOLES** to travel through time!

A **WORMHOLE**, IN RELATIVE THEORY IS RATHER LIKE A BLACK HOLE WHICH HAS NOT **QUITE** COLLAPSED INTO A SINGULARITY -

BUT OPENS OUT AGAIN INTO A **SEPARATE** REGION OF SPACETIME.

It's rather **like**...

...THE **WARDROBE** IN C.S. LEWIS'S THE LION, THE WITCH & THE WARDROBE... IN **OUR** UNIVERSE, YOU GO THROUGH A SMALL **DOOR**...

BUT THE **BACK** OF THE WARDROBE OPENS OUT INTO A **DIFFERENT** UNIVERSE - NARNIA.

A WORMHOLE CAN OPEN UP INTO **ANOTHER** UNIVERSE, OR CAN **JOIN** TWO REGIONS OF **OUR OWN** UNIVERSE.

Yeah. But **that's** just in **books**!

THE **PROBLEM** IS THAT ACCORDING TO RELATTUITY THEORY **ALONE** WORMHOLES SHOULD VERY RAPIDLY **COLLAPSE** INTO SINGULARITIES...

Hey...

BEFORE ANYONE HAS A CHANCE TO TRAVEL **THROUGH** THEM...

Yow!

BUT IT IS POSSIBLE THAT **QUANTUM** EFFECTS CAN KEEP A WORMHOLE **OPEN** RATHER LIKE THE WAY THEY **SMEAR OUT** THE SINGULARITY AT THE **BEGINNING** OF TIME.

IT WOULD BE A **SMALL** WORMHOLE - BUT NEVER MIND.

eeek!

DRINK ME

But **how** would it be used for **time travel**?

To **stop** anybody being **late**-

WHAT YOU NEED IS A WORMHOLE **JOINING** TWO BLACK HOLES **NEXT** TO EACH **OTHER** IN **OUR** UNIVERSE...

It - it's the **White Chicken**!

NOW, TAKE BLACK HOLE **B** & **WHIRL** IT ROUND WORMHOLE **A** AT NEARLY THE SPEED OF LIGHT...

But...

Don't **quibble** - this is the **easy** bit!

Black holes have **strong gravity**, OK?

SO JUST DANGLE A NICE BIG **ASTEROID** IN FRONT OF IT, & THE BLACK HOLE WILL COME **RUNNING**.

SHOOT THE ASTEROID **ROUND** & **ROUND** IN A **CIRCLE** -

& THE HOLE WILL **CHASE** IT LIKE A **DOG** CHASING ITS OWN **TAIL**...

A

B

A

B

Simple, like I said!

TIME WILL RUN MORE **SLOWLY** FOR CLOCKS NEAR **B** THAN FOR CLOCKS NEAR **A**-

B

A

Oh, my **beak & feathers**...

BUILDING UP A TIME-DIFFERENCE BETWEEN THE **TWO ENDS** OF THE **WORMHOLE**...

B

A

WHEN THE TIME DIFFERENCE IS **BIG ENOUGH** FOR YOUR NEEDS, BRING **B** TO A HALT AGAIN.

Just like **that**?

CLOCKS AT THE TWO ENDS OF THE WORMHOLE NOW **TICK** AT THE **SAME RATE** AS EACH OTHER. BUT HOLE **B** IS IN THE **PAST**.

A

B

YOU CAN JUMP THROUGH **HOLE A**-

EMERGE ALMOST **INSTANTANEOUSLY** (BY YOUR **OWN WATCH**) FROM **HOLE B**-

& FIND YOURSELF IN THE **PAST**.

Looks **exactly the same**...

IF YOU TRAVEL **QUICKLY** ENOUGH BACK TO HOLE **A** THROUGH **ORDINARY FLAT SPACE**

YOU CAN JUMP **IN** AGAIN **BEFORE** YOU JUMPED IN THE **FIRST** TIME, & GET BACK **EVEN FURTHER** INTO THE PAST...

'IF THERE **ARE** PHYSICAL LAWS WHICH **PREVENT** THE CONSTRUCTION OF SUCH A MACHINE', SAYS NOVIKOV 'WE DON'T **KNOW** OF THEM...'

Time machines?

HOW THEN, COULD THE UNIVERSE, OR THE LAWS OF PHYSICS, AVOID THE TIME TRAVEL **PARADOXES** BELOVED OF SCIENCE FICTION WRITERS?

Amateurs!

ONE SPECULATION IS THAT IF THERE REALLY **ARE** MANY WORLDS, THEN **EVERY** TIME YOU TRAVEL THROUGH SUCH A TIME MACHINE-

YOU DO NOT **REALLY** RETURN TO YOUR **OWN** PAST, BUT TO THE PAST OF SOME **ALTERNATIVE REALITY**...

Trouble **is**, I think I **come from** an alternative reality...

IF YOU **KILL GRANNY**, THEN 'YOU' NEVER GET **BORN** IN **THAT** VERSION OF THE UNIVERSE.

Oops!

SQUISH

GUILT

BUT YOUR ACTION HAS **NO** EFFECT IN THE **PARALLEL** WORLD YOU CAME FROM

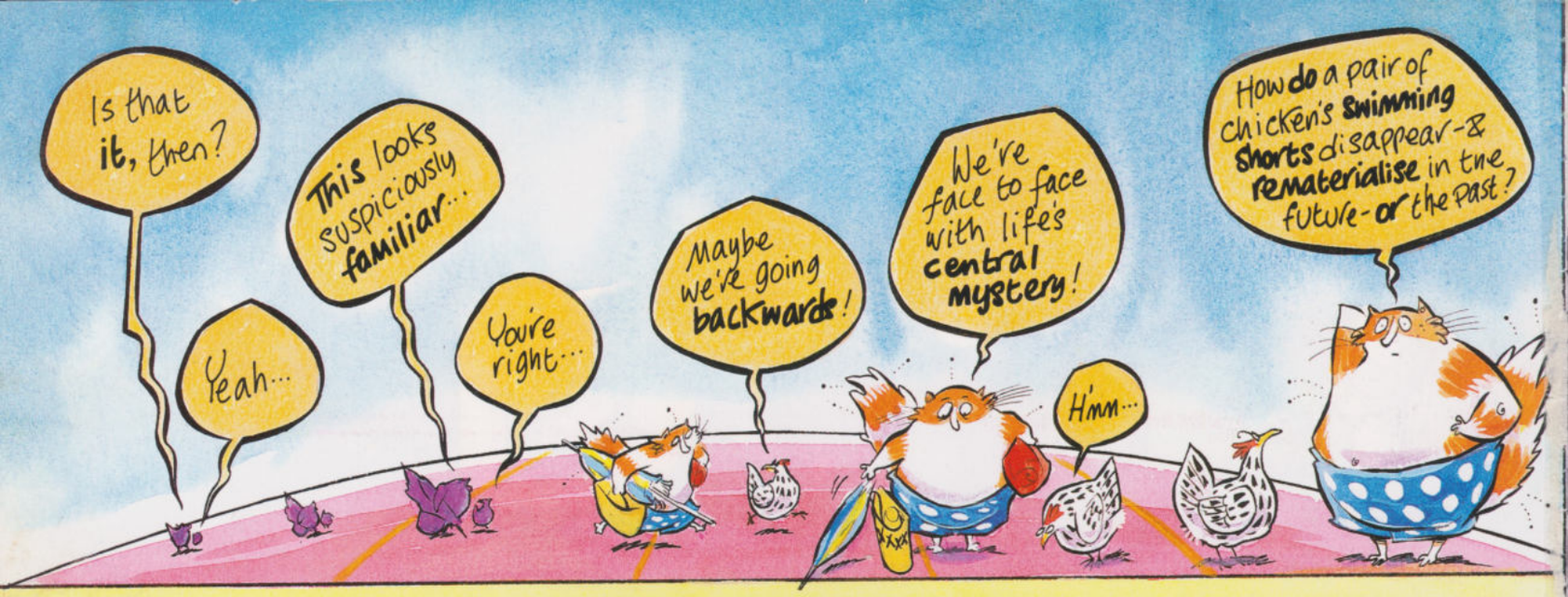
Welcome **back**...

NOVIKOV DOESN'T **BELIEVE** THIS: THORNE QUITE **LIKES** THE IDEA...

WHICH IS PROBABLY AN APPROPRIATELY **CONFUSED** NOTE ON WHICH TO **END** THE DISCUSSION. THERE MAY BE **NO** UNIQUE **HISTORY** OF **TIME**...

What **happened**?!

...But we hope you **enjoyed** the **trip**!


Is that it, then?
Yeah...
This looks suspiciously familiar...
You're right...
Maybe we're going backwards!
We're face to face with life's central mystery!
H'mm...
How do a pair of chicken's swimming shorts disappear-& rematerialise in the future-or the past?

THE CARTOON HISTORY OF TIME

BY KATE CHARLESWORTH & JOHN GRIBBIN

★ A CARDINAL BOOK ★

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JOHN GRIBBIN IS GRATEFUL TO HIS FAMILY FOR LAUGHING AT HIS JOKES

THIS BOOK IS BASED ON A LUNCH WITH GAIL VINES ★

A boring list of chapter titles and page numbers to replace the equally boring ‘blank’ inside backcover.

1. What is TIME?	Page 1
2. SPACE, TIME & the UNIVERSE	Page 11
3. CATS & QUANTA	Page 20
4. BLACK HOLES	Page 30
5. The BIRTH of TIME (Mime Version)	Page 38
6. The DEATH of TIME	Page 46
7. TIME TRAVEL	Page 54
Administration	Page 64

| Einstein’s Socks> =0

The classification of 530.11 is pinched from the OCLC record for the book.

Perhaps I should do it in LaTeX?!

Briefer, wittier, more accessible, but just as broad in scope as the other book—
THE CARTOON HISTORY OF TIME is the definitive study of Life, the Universe, & (Almost) Everything!

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